REMARKS/ARGUMENTS

The amendments and remarks hereto attend to all outstanding issues in the pending office action of 8 July 2005, as well as the December 2005 interview conducted with Examiner Chang. Claims 1-3 and 7-11 remain pending in this application. Claims 1-3 and 9-10 are cancelled. Claims 7-8 and 11 are amended. New claims 12-23 are added. No new matter has been added by these amendments.

Statement of the Substance of Dec. 6, 2005 Interview

In accordance with 37 C.F.R. §1.133 and MPEP §713.04, Applicants submit the following Statement of the Substance of Interview for the prosecution record of this application. These remarks pertain to the interview held at the USPTO in this application on 6 December 2005.

A personal interview attended by Examiner Audrey Chang of the USPTO, attorney Curtis Vock, and inventors Dr. W. Thomas Cathey and Dr. Edward Dowski was held on 6 December 2005. A draft claim set for Application No. 09/070,969 (which is related to this application, with claim amendments similar to those in this Application) was sent to Examiner Chang on 5 December 2005 in preparation for the meeting. Prior art discussed in the interview included the article "Optical/digital incoherent image processing for extended depth of field," by Ting-Chung Poon and Masoud Motamedi (hereinafter, "Poon"), U.S. Patent No. 4,804,249 to Reynolds et al. (hereinafter, "Reynolds"), and U.S. Patent No. 4,480,896 to Kubo et al. (hereinafter, "Kubo"), all of which are of record in this Application.

Independent claims of the draft claim set were discussed in the interview. Examiner Chang noted that the use of "broader" in respect to the ambiguity function was indefinite and asked that this be dealt with in the officially-filed amendment. Examiner Chang then asked exactly what the invention was. Dr. Dowski and then Dr. Cathey described how, in their view, Wavefront Coding works. Dr. Dowski then described how Poon, Reynolds and Kubo do not teach the limitations of the claims. Examiner Chang appeared to appreciate this. The inventors also provided Examiner Chang with a copy of an Applied Optics article (Cathey et al., "New paradigm for imaging systems", Applied Optics, vol. 41, no. 29, 10 October 2002, pp. 6080-6092); all parties discussed the resolution of bubbles in the figure of this article, and how

counting bubbles is an example of the importance of wavefront coding without post processing, as in certain of the present claims. It was agreed that the officially-filed Response would provide a tutorial of the technology and show how the specification supports the claim amendments. At the end of the interview, Examiner Chang requested that the references already cited in Information Disclosure Statements be grouped by category, and agreed to review the references if such a grouping is provided.

It is our contention that the above amendments and following remarks attend to Examiner Chang's requests as well as each issue raised in the present office action.

Brief Summary of Claim Amendments

Claim 7 is amended to clarify that the lens and the optical mask in the imaging system cooperate to image light from an object to form an optical image. Also, claim 7 has been amended to eliminate the language of the claim with respect to zeros of an optical transfer function and to, instead, include claim limitations related to an ambiguity function and a point spread function characterizing the imaging system, while conforming to the language used in the specification. In particular, these claims have been amended to clarify that a main lobe of the ambiguity function is broader in v for a given value of the normalized spatial frequency parameter u and the point spread function of the system has a functionally different form for a given value of ψ, in comparison to a magnitude distribution of ambiguity function and PSF, respectively, characterizing the imaging system without the optical mask for those given values of u and ψ, over an extended depth of focus larger than a depth of focus formed without the optical mask. The amendments are supported, for example, by paragraphs **[0011]**, **[0070]**, **[0102]** and **[0113]** of the specification (see also paragraph (8) of the Rule 132 Affidavit filed with the Response to Office Action of 5 May 2005).

The tutorial provided below in response to Examiner Chang's request further describes details of these amendments in view of the understanding by the inventors. Other grammatical redundancies in the claim have also been corrected.

Claim 8 is amended to conform to the language of claim 7 as well as to clarify that the post-processor processes the optical image detected at the detector to remove imaging effects

induced by the optical mask. These amendments are supported, for instance, by paragraph [0094] of the specification as filed.

Claim 11 is amended to add a definition of the misfocus parameter ψ. In particular, the definition of the misfocus parameter from paragraph [0075] of the application as filed is incorporated into the claim in order to clarify the meaning of the variable ψ.

No new matter is added to the application through any of the claim amendments.

New claims 12-23 are added with full support of the specification as filed.

New claim 12 adds a specific range for the range of the misfocus parameter ψ as recited in claim 11.

New claim 13 adds the limitation that the optical mask is formed integrally with the lens. This amendment is supported in the specification as filed at, for example, paragraph [0120] and FIG. 45.

New claim 14 is similar to cancelled claim 1 but utilizes language like that of pending claim 7. The limitations in claim 13 are supported, for example, by paragraphs [0011], [0070] and [0072] of the application as filed.

New claim 15 is similar to cancelled claim 3 but utilizes language like that of pending claims 7 and 8 as supported, for example, by paragraph [0094] of the application as filed.

New claim 16 is similar to cancelled claim 9 but utilizes language like that of pending claim 7. The limitations in claim 15 are supported, for example, by paragraphs [0073] of the application as filed and paragraph (8) of the Rule 132 Affidavit filed on 5 May 2005.

New claim 17 is similar to cancelled claim 10 but utilizes language like that of pending claims 7 and 8 as supported, for example, by paragraph [0094] of the application as filed.

New claim 18 is similar to cancelled claim 1 but with claim limitations defined in terms of an ambiguity function and a point spread function rather than an optical transfer function. Such language is supported in the application as filed at, for example, paragraph [0072].

New claim 19 is similar to cancelled claim 3 but depends from and conforms to the point spread function language of claim 18. The limitations recited in claim 19 are supported, for instance, in paragraph **[0094]** of the application as filed.

New claim 20 is similar to pending claim 7 but with claim limitations defined using ambiguity function and point spread function language as supported, for example, in paragraph **[0072]** of the specification as filed.

New claim 21 is similar to pending claim 8 but depends from and conforms to the point spread function language of claim 20. Such limitations are supported, for example, in paragraph **[0094]** of the application as filed.

New claim 22 adds a limitation that the optical mask is configured to implement a cubic phase modulation, as supported, for instance, by paragraphs **[0077]** – **[0080]** and FIG. 3 of the application as filed.

New claim 23 adds a limitation that the optical mask is integrally formed from the lens. This limitation is supported in the specification as filed at, for example, paragraph **[0120]** and FIG. 45.

No new matter has been added by the new claims.

Tutorial of Wavefront Coding – As Requested by Examiner Chang

The following provides a brief comparison between the art of record and the disclosure of the present application as filed, as requested by the Examiner at the Interview of December 6, 2005.

A unmodified, traditional imaging system (without Wavefront Coding (WFC)) is a good starting point for comparing imaging systems. An ideal, unmodified imaging system is understood to be one characterized by a pupil function that is constant across the aperture. An example of an unmodified imaging system is, for instance, the "standard optical system" shown in Figure 1 of the application as filed, including a lens 25 for imaging an object 15 therethrough onto a charge-coupled device (CCD) or complementary metal oxide semiconductor (CMOS) sensor 30.

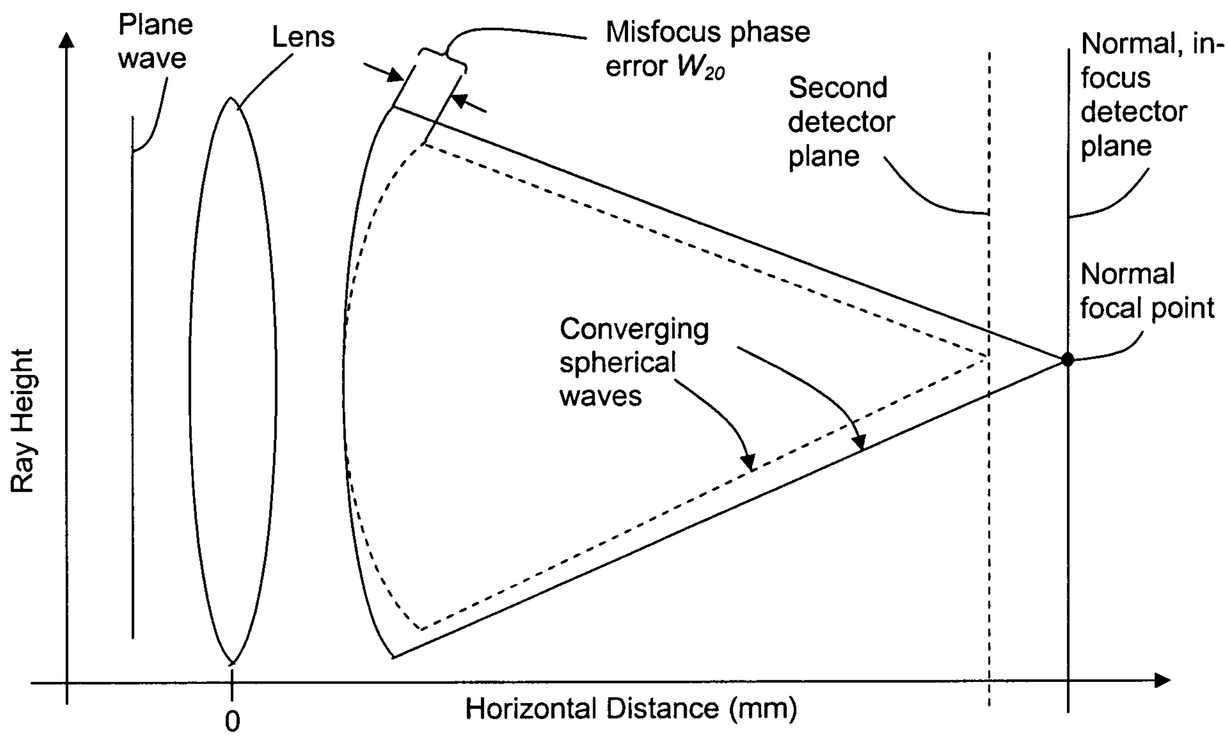

FIG. 1. Phase difference of two converging spherical waves.

Another example is shown in FIG. 1 above. This type of system is also referred to as a diffraction-limited imaging system in the optics literature. A diffraction-limited system is known in the art to be an ideal system. Such an ideal system is essentially impossible to construct in practice due to the presence of numerous aberrations, or non-ideal characteristics, in real imaging systems. However, these aberrations, if small enough, are often ignored when considering theoretical performance of an imaging system.

FIG. 1 shows a plane wave focused by a lens, and illustrates the phase error that results when the detector plane is moved closer to a one-dimensional lens from the normal focal point. A perfect lens will produce a spherical wave (indicated by dashed lines) that focuses to a point, shown as the normal focal point in FIG. 1, and an in-focus image would result at the normal detector plane. If the detector plane is moved closer to the lens (e.g., away from the best focus position to the position of the second detector plane in FIG. 1), the spherical wave that would converge to the new location must be more curved (as indicated by solid lines). The phase difference between these two spherical waves at their extreme ends is referred to as a misfocus

phase error, also known as aberration W_{20}, as first described by Hopkins (H.H. Hopkins, "The Aberration Permissible in Optical Systems," Proc. Phys. Soc. LXX, 5 – B, 1957, pp. 449 – 470). The "2" in the subscript of the misfocus phase error refers to a quadratic function in radius, and the "0" in the subscript refers to no variations in angle, in a cylindrical co-ordinate system. W_{20} is related to a misfocus parameter ψ by the equation:

$$\psi = 2\pi \frac{W_{20}}{\lambda} \qquad \text{(Eq. 1),}$$

where λ is the wavelength of the light rays.

In general, for a given imaging system (e.g., a lens with a lens length L, a focal length f with a given object distance d_o and image distance d_i for imaging light with wavelength λ), the misfocus parameter ψ is given by the equation:

$$\psi = \frac{L^2}{4\pi\lambda}\left(\frac{1}{f} - \frac{1}{d_o} - \frac{1}{d_i}\right) \qquad \text{(Eq. 2)}$$

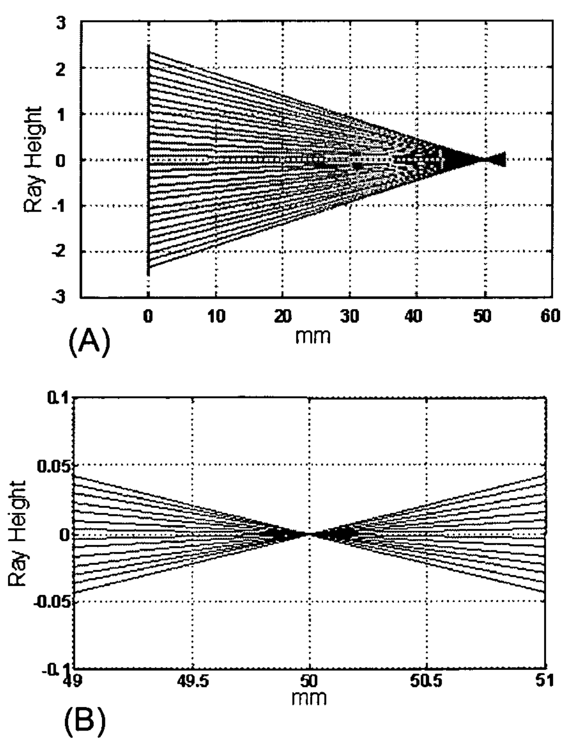

FIG. 2. Propagating rays through an unmodified, one-dimensional lens located at 0 mm, illustrated as a plot of ray height as a function of horizontal position.

Ideal light rays approaching the lens of FIG. 1 propagate perpendicular to the wave front, and come to a focus as shown in FIG. 2(A). FIG. 2(B) shows the details of the ray convergence at the horizontal position of 50 mm of the rays of FIG. 2(A).

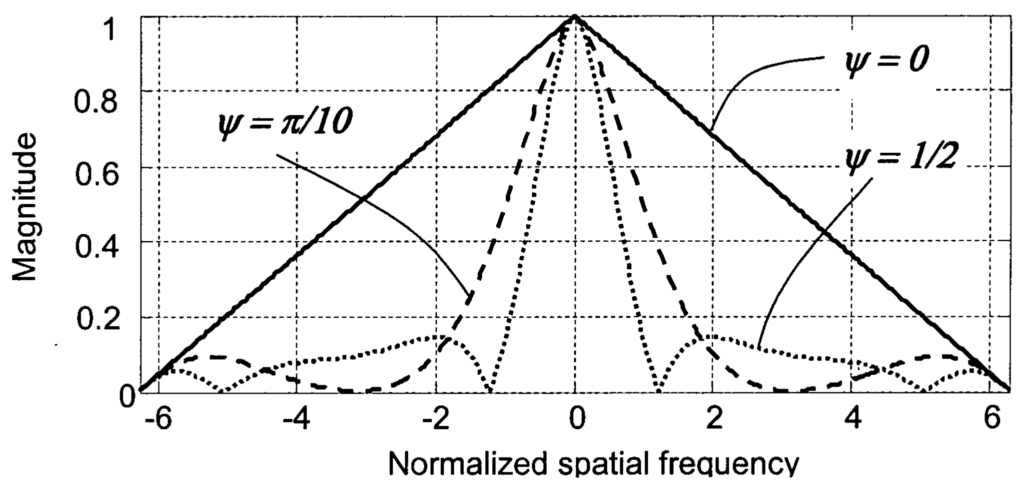

FIG. 3. OTF of an unmodified imaging system for three values of misfocus parameter.

The Fourier transform of the PSF of an imaging system results in an optical transfer function (OTF) of the imaging system as a function of spatial frequency (e.g., in units of cycles per mm). The magnitude of the optical transfer function is called the modulation transfer function (MTF), which is related to the effect of the imaging system on the magnitude of the spatial frequencies of the information traveling from the object, through that imaging system and to the detector plane. The OTF of the unmodified, traditional imaging system as a function of normalized spatial frequency u, for three values of misfocus parameter ψ is shown in FIG. 3. Note that the curves corresponding to values of $\psi = 0$ and $\psi = 1/2$ correspond to Fig. 6 and Fig. 7, respectively, of the application as filed. It is noted that the maximum theoretical range of the normalized spatial frequency ψ is $\pm 2\pi$.

A one-dimensional pupil function system (such as the normalized one-dimensional pupil function $\hat{P}(x)$ for normalized spatial parameter x as discussed on pages 15-16 of the application

as filed) is considered herein for simplicity. Extensions of the presently considered concepts to two dimensions have equivalent fundamental properties; that is, for example, an imaging system with a rectangular aperture may be considered as a combination of two, one-dimensional systems. As described near the top of page 16 of the application as filed, the OTF for a general imaging system for a one-dimensional pupil function is given by:

$$H(u,\psi) = \int \left(\hat{P}\left(x + \frac{u}{2}\right) e^{i\left(u + \frac{x}{2}\right)^2 \psi} \right) \left(\hat{P}^*\left(x - \frac{u}{2}\right) e^{-i\left(u - \frac{x}{2}\right)^2 \psi} \right) dx \qquad \text{(Eq. 3)}$$

As may be seen in FIG. 3, the OTF of an unmodified, one dimensional imaging system with zero misfocus ($\psi = 0$) has a triangular shape (as also shown in Fig. 6 of the application as filed). The notable feature of the OTF of the unmodified, ideal imaging system with zero misfocus is that the magnitude of the OTF does not exhibit any zeros (i.e., spatial frequencies at which the magnitude of the OTF is zero) within a given range of normalized spatial frequency values ($-2\pi < u < 2\pi$, in the example shown in FIG. 1). This feature of the ideal OTF exhibiting non-zero magnitude over a range of normalized spatial frequency values is particularly attractive because it indicates that no image spatial frequency information is lost during the imaging process by this ideal imaging system for images in this range of normalized spatial frequency values.

Aberrations in an imaging system act to decrease the magnitude of the OTF at particular spatial frequencies. These aberrations may be misfocus-like aberrations, such as misfocus, astigmatism, spherical aberrations, astigmatism or chromatic aberration, or other aberrations like coma. For example, for a small amount of misfocus (e.g., $\psi = \pi/10$ as shown in FIG. 3) the OTF may decrease overall while going to essentially zero at two values of normalized spatial frequency within the range of normalized spatial frequencies shown in the figure. As may be seen in FIG. 3, the OTF for this small value of misfocus ($\psi = \pi/10$) is dramatically different from the OTF for zero misfocus ($\psi = 0$). In the case of mild misfocus ($\psi = \pi/10$), the range of normalized spatial frequency over which the OTF exhibits no zeros (i.e., the width of the main OTF peak) has been reduced to $-3 < u < 3$, indicating that image information for images having spatial frequencies outside of this range would be lost during the imaging process through this imaging system with mild misfocus.

For larger amounts of misfocus (such as $\psi = 1/2$), the OTF may exhibit numerous zeros within the range of normalized spatial frequencies shown while the width of the main OTF peak is further narrowed (also see Figure 7 of the application as filed). Figure 8 of the application as filed shows the OTF for an even greater value of misfocus ($\psi = 3$), which exhibits numerous values of normalized spatial frequency where the magnitude of the OTF is essentially zero.

While the OTF gives an accurate characterization of the modulation of an imaged object as a function of spatial frequency, a particular OTF curve gives information only for a given value of misfocus. Another characterization tool for imaging systems is the Ambiguity Function (AF). The AF, first proposed by P. M. Woodward (P. M. Woodward, *Probability and Information Theory with Applications to Radar*, Pergamon, New York, 1953), may be interpreted as a visualization of the OTF of an imaging system for all values of misfocus for a range of normalized spatial frequency values on the same plot. That is, the modulation of the imaging system for all values of misfocus may be qualitatively evaluated by visual inspection of the AF. Specific systems may also be designed efficiently and accurately through quantitative evaluation of the AF. The AF is related to the OTF by the following equation:

$$H(u,\psi) = A\left(u, \frac{u\psi}{\pi}\right) \qquad \text{(Eq. 4)}$$

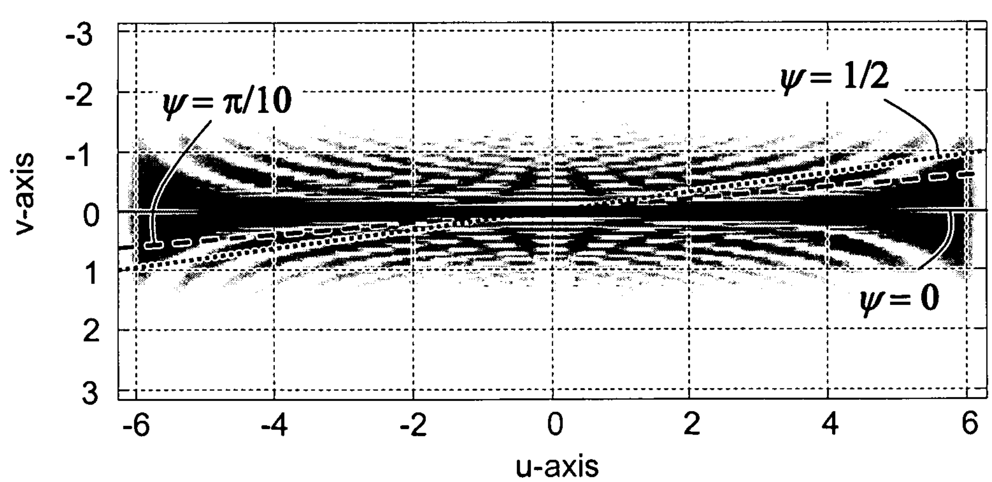

FIG. 4. AF of an unmodified, traditional imaging system

The AF related to the pupil of a unmodified, traditional imaging system is shown in FIG. 4. This figure is essentially the same as Fig. 5 in the application as filed. The AF was originally developed as a tool to analyze radar systems. It is common to label the axes of the AF as u-axis for the horizontal axis and v-axis for the vertical axis. In terms of an imaging system, the u-axis represents spatial frequency analogous to the horizontal axis of OTF plots. While the vertical axis has no direct relationship to imaging systems, the projection of radial slices of the AF onto the horizontal axis may be interpreted as the OTF of this imaging system for various amounts of misfocus. That is, the AF shown in FIG. 4 may be interpreted as a three-dimensional function, with the density of the grayscale indicating the height out of the page (i.e., darker shades corresponds to higher OTF magnitude), the horizontal axis representing a normalized spatial frequency, and the angle measured from the horizontal axis corresponding to the misfocus parameter ψ.

The AF is useful because it enables the visualization, in a single graphic, of the range of OTFs for a one-dimensional imaging system through a range of object and/or image distances. That is, the AF may be regarded as a plot of OTFs arranged in a radial fashion where the angle between a radial line and the horizontal axis determines the degree of misfocus of the OTF. For example, a horizontal slice of the AF, or a radial line through the origin with a slope of zero, corresponds to the OTF with zero misfocus.

For a given value of normalized misfocus ψ, the slope of the radial line that produces the OTF with that amount of misfocus is given by ψ/π. The projection to the u-axis of the AF modulation under the radial lines labeled $\psi = 0$, $\psi = \pi/10$ and $\psi = 1/2$ of FIG. 4 yield exactly the OTFs with misfocus values $\psi = 0$, $\psi = \pi/10$ and $\psi = 1/2$ as shown in FIG. 3. It may be observed by inspection of FIG. 4 that, for increasingly larger values of ψ (i.e., for radial lines with larger slope), the modulation of the AF will continue to fall. That is, the lighter shading of the AF away from the horizontal axis indicates reduced modulation of the AF (where the horizontal, v = 0 axis corresponds to the misfocus value $\psi = 0$).

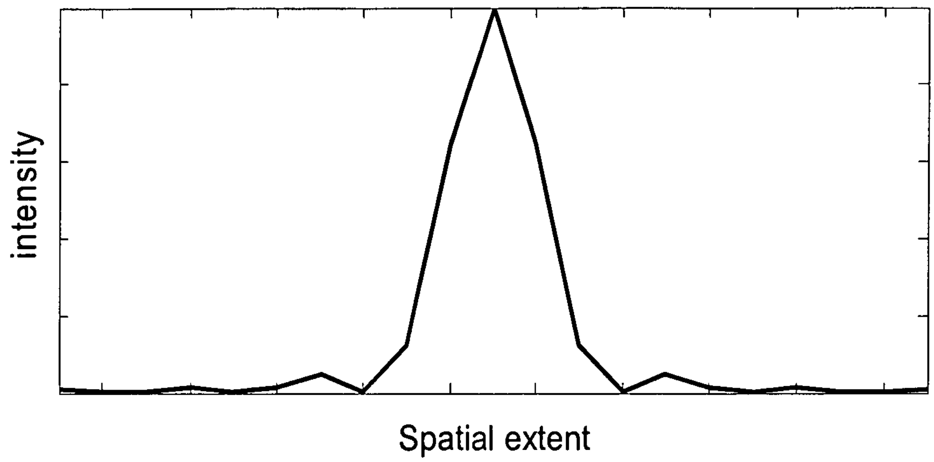

FIG. 5. Calculated PSF of an unmodified, traditional imaging system with no misfocus.

FIG. 5 shows a calculated PSF of the unmodified, traditional imaging system with zero misfocus. FIG. 5 corresponds to Fig. 17 of the application as filed, except for the choice of horizontal and vertical scales, and resolution of the data plotted. As noted earlier, the PSF is related to the OTF through a Fourier transform. Therefore, the PSF of the unmodified, traditional imaging system with zero misfocus is obtained by calculating the inverse Fourier transform of a triangle function as shown in FIG. 3. From knowledge of Fourier transform relationships, it is readily deduced that the functional form of the PSF is then a *sinc*-squared function, where the *sinc* function is defined as: $sinc = (1/x)\sin(x))$; and the *sinc*-squared function is $sinc^2 = (1/x^2)(\sin(x))^2$. It is known that, if the imaging system exhibits aberrations, then the OTF is no longer a triangular function and the PSF is no longer a *sinc*-squared function. However, it is emphasized that the PSF of the unmodified, traditional imaging system with zero misfocus has the functional form of a *sinc*-squared function.

Stopped Down Imaging Systems

A stopped down imaging system is related to a traditional unmodified imaging system but with a reduced aperture size. The reduction of the aperture size results in decreased sensitivity of the system to misfocus, reduced spatial resolution of the optics and decreased amount of light gathered by the imaging system. The functional form of the stopped down zero

misfocus PSF is substantially the same (i.e., having only a scale change) as the zero misfocus, unmodified traditional imaging system.

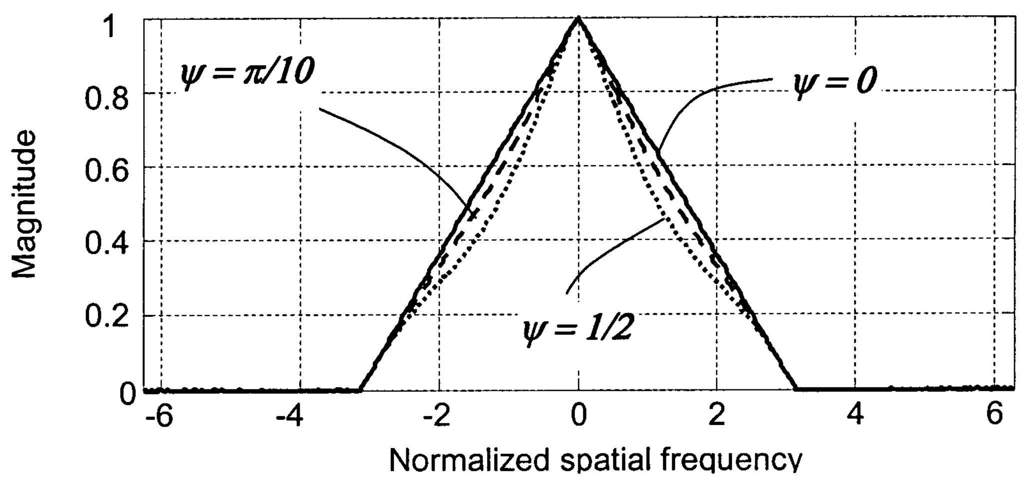

FIG. 6. OTFs of a stopped down imaging system for three values of misfocus.

FIG. 6 shows the OTF of a stopped down imaging system with three different values of misfocus, corresponding to those shown in FIG. 3. The aperture has been reduced to one-half of the unmodified, traditional imaging system discussed earlier. While FIGS. 3 and 6 are shown to be normalized to one, in practice, the OTF peak falls as the square of the ratio of the diameters of the stopped-down and the full aperture. The peak of the non-normalized OTF at zero spatial frequency is equal to the area under the PSF curve, and is related to the number of photons captured by the lens.

There are two important differences between the OTFs of the traditional unmodified system of FIG. 3 and the stopped down system of FIG. 6. First, the OTFs for the stopped down system vary much less than those of the full aperture, unmodified system for the same values of ψ. The second important difference is that the magnitude of the OTF of the stopped down system is substantially zero beyond a normalized spatial frequency value of π. This second difference is due to the fact that the size of the aperture of the stopped down system is one-half that of the full aperture system. This reduction of the aperture size by a factor of two leads to a loss of intensity (i.e., photons) at the image plane. This intensity loss is not seen in the

normalized vertical axes of the OTFs of FIG. 6. In a two-dimensional system with a square aperture, for example, the intensity loss would be by a factor of four.

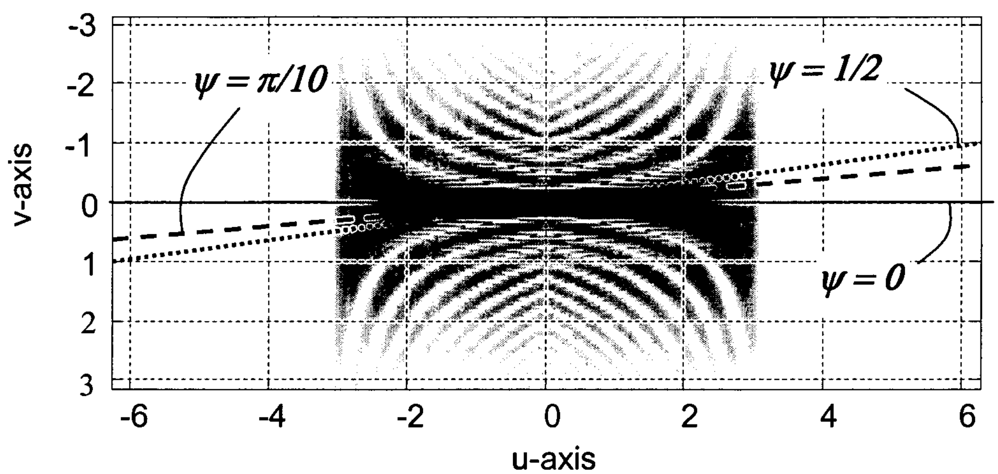

FIG. 7. AF of an unmodified, traditional imaging system that has been stopped down by a factor of two.

The AF related to the stopped down imaging system is shown in FIG. 7. There are again two main differences between the AFs of the stopped down system and the traditional unmodified system as shown in FIG. 4. First, the main lobe (i.e., the dark region near the $v = 0$ line) of the AF of the stopped down imaging system is slightly broader or wider in the v-direction for a given value of u than the main lobe AF of the traditional unmodified imaging system for a given value of misfocus. That is, the central dark region of the AF of the stopped down system in FIG. 7 around the $v = 0$ line is slightly broader or wider in the vertical direction for a given u-axis value (i.e., normalized spatial frequency value) than in the traditional unmodified system as shown in FIG. 4. In other words, radial lines of steeper slope, corresponding to larger values of misfocus ψ, are required to intersect the light regions of the AF such that the OTF includes zeros, as compared to in the AF of the unmodified, traditional system. In such cases, when the AF of the stopped down imaging system is slightly broader in the misfocus domain compared to the unmodified traditional system, the modified, stopped down system will exhibit a slightly reduced sensitivity to misfocus. However, there is still a significant concentration of the AF intensity in the immediate vicinity of the $v = 0$ line.

The other main difference between the AFs of the stopped down and unmodified system is the horizontal extent of the AF. It may be seen in FIG. 7 that the horizontal extent of the stopped down AF is ½ as large as that of the unmodified, traditional system. In the example illustrated in FIG. 7, the horizontal extent of the AF of the stopped down system is exactly one half as large as that of the full aperture unmodified system. That is, the spatial resolution of the stopped down system is reduced accordingly.

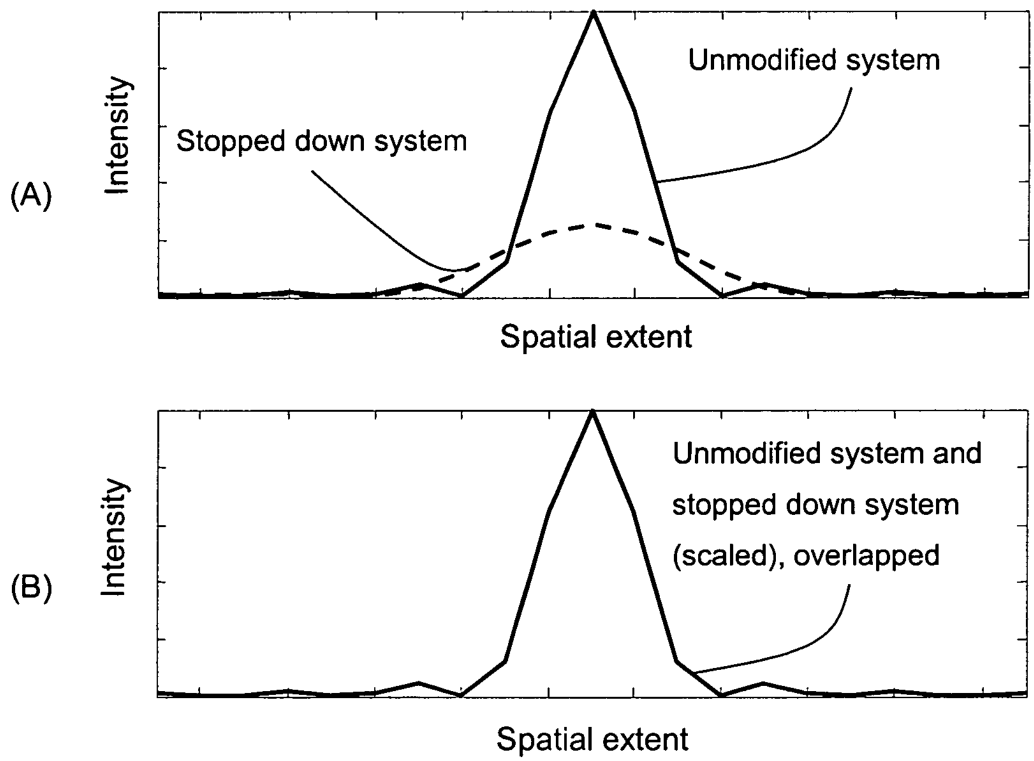

FIG. 8. A comparison of the PSFs of the unmodified, traditional imaging system and the stopped down, modified system for zero misfocus ($\psi = 0$). FIG. 8(A) does not include scaling, and FIG. 8(B) includes scaling of the PSF of the stopped down system in both the horizontal and vertical directions.

The zero misfocus ($\psi = 0$) PSF of the stopped down system is compared with that of the unmodified, traditional imaging system in FIGS. 8(A) and 8(B). As may be seen in FIG. 8(A), the PSF of the stopped down, zero misfocus imaging system is, at first glance, wider horizontally

and shorter vertically than that of the zero misfocus PSF of the unmodified, traditional imaging system, which was earlier shown in FIG. 5. The increased width of the stopped down system PSF is due to the decrease in the horizontal extent of the AF and OTF of the stopped down system over those of the unmodified, traditional imaging system. The PSF of the stopped down system is shorter vertically (i.e., is reduced in intensity) as compared to that of the unmodified system because the reduced aperture allows only ½ of the number of photons into the stopped down system as compared to in the unmodified, full aperture system. In other words, the sum of all the PSF values for a particular value of misfocus for the ideal, stopped down system is one half that of the sum of the all the PSFs values for the same value of misfocus for the ideal, unmodified, traditional imaging system.

It is notable, however, that the aperture size of the full aperture, unmodified, traditional imaging system is arbitrary. That is, the stopped down system presently under discussion may be considered as a scaled version of the unmodified, traditional imaging system. This fact implies that the functional form of the PSF of an unmodified, traditional imaging system is independent of the size of the aperture.

In general, if a given imaging system exhibits a particular PSF having a mathematical form of:

$$PSF_0(x) = h(x) \qquad \text{(Eq. 5),}$$

where x is an independent spatial variable, then another PSF (e.g., PSF_1) may be characterized as having the same functional form as PSF_0 if:

$$PSF_1(x) = a \cdot h(bx) \qquad \text{(Eq. 6)}$$

for some non-zero constants a and b.

In comparing FIGS. 3 and 6, it may be seen that the OTF of the zero misfocus, stopped down imaging system has a triangular form with one half the width and one half the total sum (i.e., the area under the OTF curve) of the unmodified, traditional imaging system with zero misfocus. From knowledge of the properties of the Fourier Transform, it may be deduced that the spatial dimension of the PSF of the stopped down system is twice as broad and the maximum PSF intensity is one fourth as large as those of the unmodified, traditional imaging system.

Therefore, the functional form of the PSF of a one-dimensional, stopped down system with aperture one half of the unmodified, traditional imaging system may be expressed as:

$$PSF_{\text{stopped\_down}}(x) = \frac{1}{4} PSF_{\text{unmodified}}\left(\frac{1}{2}x\right) \qquad \text{(Eq. 7)},$$

i.e., $a = ¼$ and $b = ½$ in (Eq. 6). Generally, for a one-dimensional, stopped down system with aperture size *S*, where $S \leq 1$, the functional form of the PSF of this stopped down system may be expressed in terms of the PSF of the unmodified, traditional imaging system as:

$$PSF_{\text{general\_stopped\_down}}(x) = S^2 \cdot PSF_{\text{unmodified}}(S \cdot x) \qquad \text{(Eq. 8)}.$$

In the present example, the PSF of the stopped down system (the dashed curve in FIG. 8(A)) is related to the PSF of the unmodified, traditional imaging system by (Eq. 7). Consequently, as shown in FIG. 8(B), the PSF of the stopped down system may be scaled vertically and horizontally such that the scaled PSF of the stopped down system overlaps the PSF of the unmodified, traditional system. In other words, the PSF of the stopped down system has the same *sinc*-squared, functional form as the PSF of the unmodified, traditional system.

Stepped Phase Imaging Systems

A stepped phase imaging system is essentially a series of stopped down systems that are arranged to form statistically independent images on the same image plane. The spatial resolution is determined by the size of an individual step while the total number of photons collected by the imaging system is determined by the collective size of the steps.

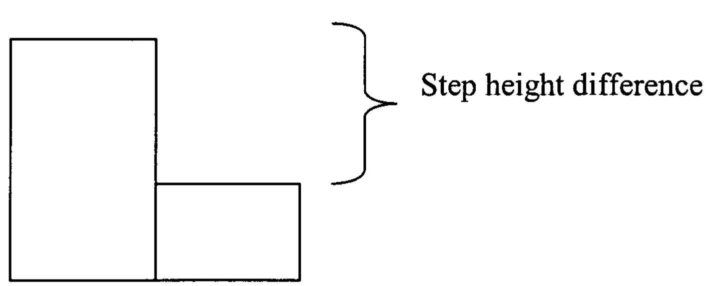

FIG. 9. Aperture layout of a two-level, stepped phase system.

FIG. 9 shows the aperture layout of a two-level, stepped phase system. Each step in FIG. 9 is shown to be optically flat, and the difference in step height is assumed to exceed the coherence length of the illumination such that the steps may be referred to as incoherent steps. If the aperture includes more than two steps (e.g., in a two-dimensional system including four steps), then the smallest difference between any two steps must exceed the coherence length of the illumination. When the step height difference exceeds the coherence length of the illumination, the light that passes through a particular step is statistically incoherent with the light passing through any other step. This incoherence allows the imaging aperture corresponding to each step to form a sub-image independent of all other regions of the aperture. The image formed at the image plane is then the composite of these sub-images.

The fundamental image forming properties of a stepped phase system are determined by the linear size (in two dimensions) of each incoherent step. The total number of photons collected by the system is determined by the total area of all incoherent steps, which is the total area of the aperture. For the one-dimensional system of FIG. 9, for example, each incoherent step occupies one-half of the aperture. The corresponding OTFs and AF of this stepped phase system of FIG. 9 are then the same as those shown for the stopped down system of FIGS. 6 and 7, respectively, since each incoherent step acts as an independent, stopped down ½ aperture imaging system. It is noted that, since the intensity axes of the AF and OTF of FIGS. 7 and 8, respectively, are normalized, the actual intensity difference between a single stopped down aperture and the two incoherent steps of the stepped phase system cannot be directly compared using these particular plots. However, it may be deduced that the insensitivity of the AF and OTF to misfocus and the reduction of the horizontal extent of the AF and OTF for the two-level, stepped phase system are the same as those of the one-half aperture, stopped down system, again since each incoherent step acts as an independent, stopped-down ½ aperture system.

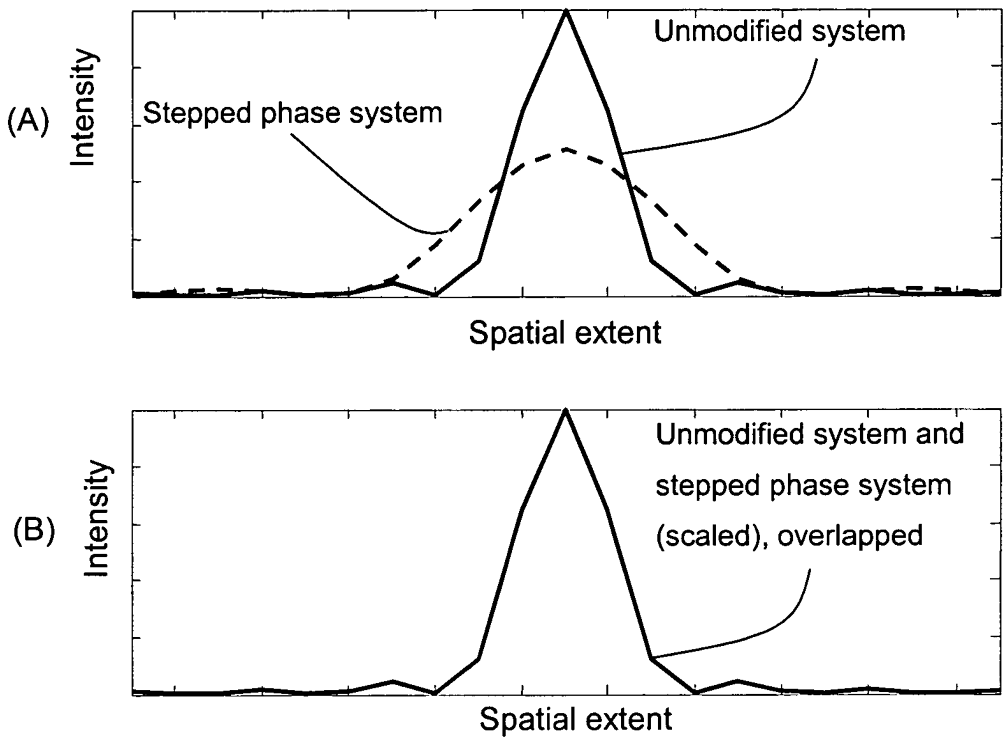

FIG. 10. A comparison of the PSFs of the unmodified, traditional imaging system and the modified, stepped phase system for zero misfocus ($\psi = 0$).

Referring now to FIGS. 10(A) and 10(B) in conjunction with FIGS. 5, 8(A) and 8(B), it is shown that the functional form of the PSF of the two-level, stepped phase system is the same as those given in (Eq. 5) and (Eq. 6) and does not differ from the PSF of the one-half aperture stopped down system in appearance. That is, there is only an intensity difference between the PSFs of: a) the unmodified, traditional imaging system; b) the stopped down system; and c) the stepped phase system.

It was earlier shown in FIGS. 8(A) and 8(B) that the PSF of the stopped down system has the same functional form of a *sinc*- squared function as the PSF of the unmodified, traditional system. Similarly, the unscaled and scaled PSFs of the stepped phase system are shown in comparison with the PSF of the unmodified, traditional system in FIGS. 10(A) and 10(B). The PSF of the stepped phase system for zero misfocus ($\psi = 0$), shown in FIG. 10(A), may be compared with the zero misfocus PSF of the stopped down system shown in FIG. 8(A). It may

be seen that the locations of the first zeros on the PSFs of the stepped phase system and the stopped down systems are the same but the maximum intensity of the stepped phase system is twice that of the stopped down system. This difference in maximum intensity between the PSFs of the stepped phase system and that of the stopped down system is due to the smaller total aperture size of the stopped down system.

From the properties of the Fourier Transform, the relationship between the PSF of the stepped phase system and the PSF of the unmodified, traditional imaging system may be expressed as:

$$PSF_{\text{stepped\_phase}}(x) = \frac{1}{2} PSF_{\text{unmodified}}\left(\frac{1}{2}x\right) \qquad \text{(Eq. 9).}$$

That is, the functional form of the PSF of the stepped phase system is the same, *sinc*- squared functional form as the PSF of the unmodified, traditional imaging system. In terms of (Eq. 6), the PSF of the stepped phase system is related in functional form to the PSF of the unmodified, traditional imaging system with constants $a = b = ½$.

FIG. 10(B) shows the scaling of the PSF of the stepped system in both the horizontal and vertical directions, thus further indicating that the functional form of the PSF of the modified, stepped phase system is the same as that of the unmodified, traditional imaging system. As it was shown earlier that the functional form of the PSF of the stopped down system is also the same as that of the unmodified, traditional imaging system, it is therefore shown that the functional form of the PSFs of the stepped phase system, the stopped down system and the unmodified, traditional imaging system are all the same *sinc*-squared function.

Wavefront Coded (WFC) System

Applicants have disclosed, in the present application as filed, techniques for extending the depth of field of optical systems by incorporating a special purpose optical mask into the optical system. Such a special purpose optical mask may, for example, add a cubic phase function to light propagating therethrough.

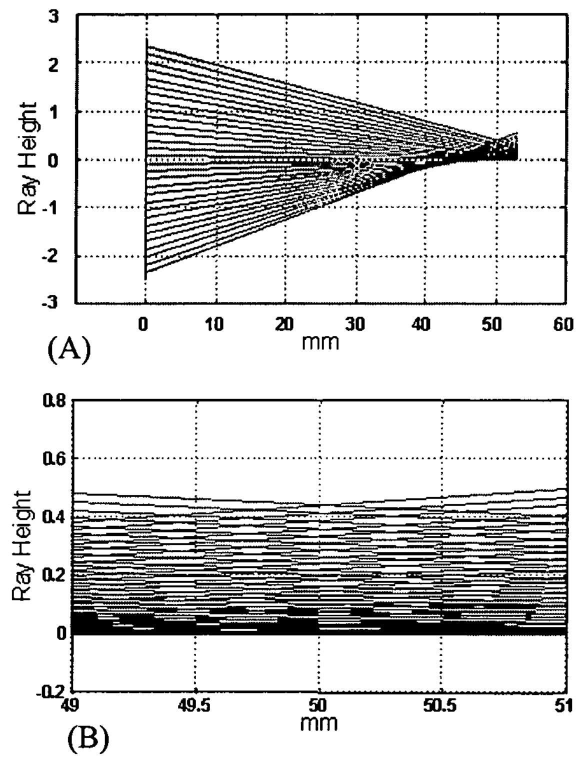

FIG. 11. Propagating rays through a WFC one-dimensional lens located at 0 mm, illustrated as a plot of ray height as a function of horizontal distance.

The ray propagation through an exemplary one-dimensional lens with an added cubic phase function is illustrated in FIG. 11(A), with the details around the former point of convergence at a horizontal distance of 50 mm shown in FIG. 11(B). The rays shown in FIGS. 11(A) and 11(B) are for an ideal one-dimensional lens with an added cubic phase function. As may be seen in comparing FIGS. 11(A) and 11(B) with FIGS. 2(A) and 2(B) for the unmodified, one-dimensional lens, the addition of the cubic phase function to the lens affects the ray propagation therethrough such that the rays do not converge at a point. This effect of the cubic phase function provides unexpected advantages, as described in detail in the present application as filed in, for example, paragraphs **[0080]** through **[0082]**.

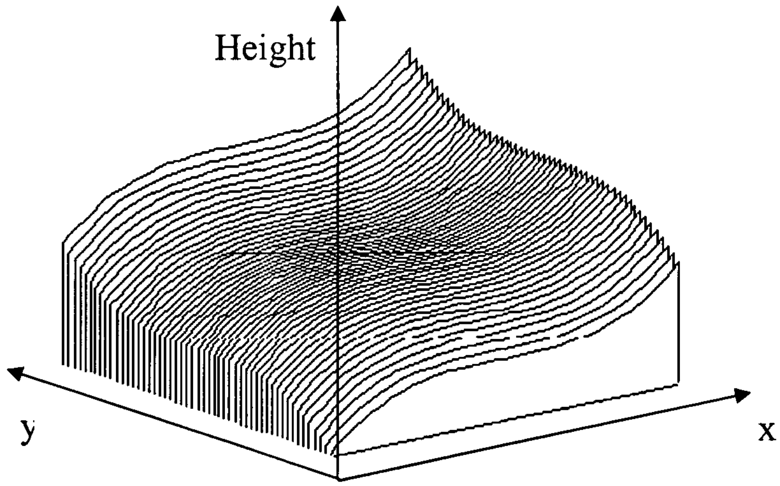

FIG. 12. The profile of a cubic phase function.

FIG. 12 shows the height profile of an exemplary cubic phase function suitable for use in the special purpose optical mask (e.g., as described in the present application as filed), illustrating the phase change that is added to a converging spherical wave traveling therethrough. The equation for the height of the function shown in FIG. 12 is $height = a\ (x^3 + y^3)$, where a is a constant that determines the maximum distance from the highest point to the lowest point. If a cubic phase function, as shown in FIG. 12, is placed on or near the one-dimensional lens, the rays no longer converge at a focal point, but take the paths shown in FIGS. 11(A) and 11(B). This process of modifying the wavefront of light traveling through an optical system with a predetermined phase function is one example of Wavefront Coding (WFC).

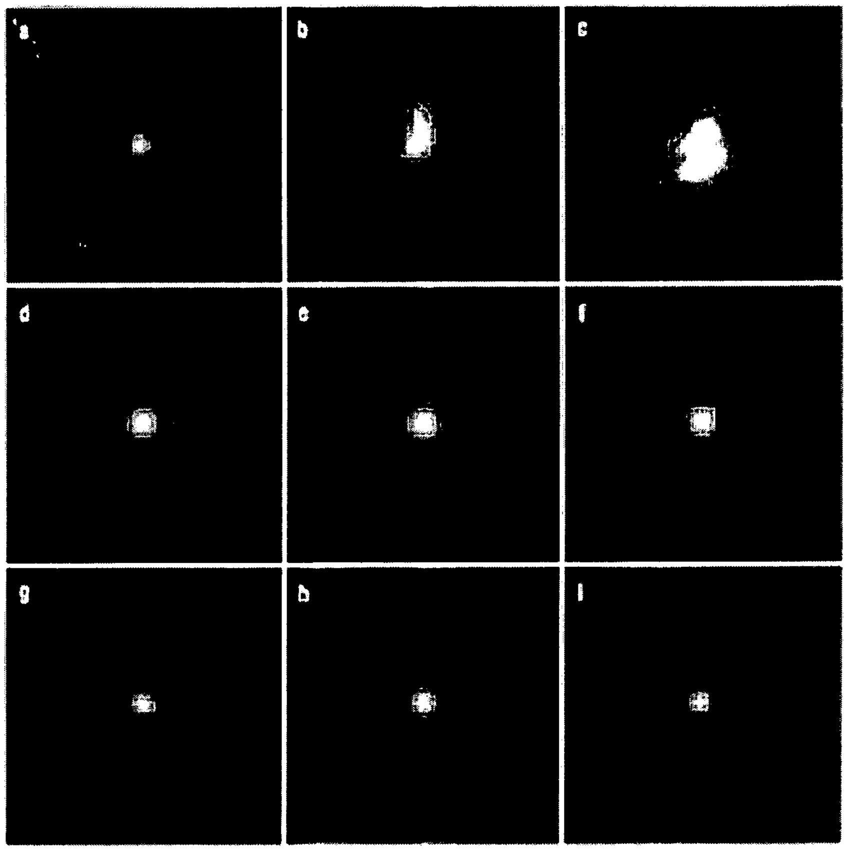

FIG. 13. Top row: images from a traditional microscope, middle row: images from a WFC microscope, and bottom row: processed images from a WFC microscope.

FIG. 13 shows a series of images of a point formed with a microscope without and with WFC. In the parlance of the art, these images are often referred to as point spread functions (PSFs), which correspond to the response of a given optical system to a point object and help characterize that given optical system. The top row (FIGS. 13(a) through 13(c)) shows experimental images of a point source obtained with a unmodified, traditional microscope when the detector array is moved away from the best focus position (as shown in FIG. 13(a)) to positions yielding out-of-focus images (FIGS. 13(b) and 13(c)). While effects due to a variety of aberrations are present in these experimental results, the major factor for the reduction in image quality is misfocus.

The middle row of FIG. 13 (i.e., FIGS. 13(d) through 13(f)) shows the corresponding images of a point source when WFC is included in the microscope and the detector array is

moved from the in-focus position (as shown in FIG. 13(d)) to the same out-of-focus positions of FIGS. 13(b) and 13(c) (shown in FIGS. 13(e) and 13(f)). In the present example, the two-dimensional cubic function shown in FIG. 12 is used in the WFC process. As may be seen in comparing FIGS. 13(d) through 13(f), the addition of WFC results in a substantially uniform series of PSFs even when the detector in the microscope is moved away from the plane of best focus. This result is in contrast with the images obtained with the unmodified, traditional microscope, which yields drastically varying PSFs depending on the position of the detector.

The present application as filed further provides post-processing the WFC image data in order to further improve image quality for a range of object and/or image distances (See, for example, paragraph **[0094]**). The post-processing may be performed in several ways. For example, the WFC image may be deconvolved with the point spread function to obtain the final image, or the Fourier transform of the image may be divided by the optical transfer function of the modified imaging system.

The bottom row of FIG. 13 (i.e., FIGS. 13(g) through 13(i)) shows the PSFs after signal processing of the WFC images of the middle row of FIG. 13. In this case, the same digital processing filter is applied to all three images of FIGS. 13(d) through 13(f) to result in the PSFs shown in FIGS. 13(g) through 13(i), respectively. It may be seen, in comparing the PSFs shown in FIGS. 13(a) through 13(c) with the PSFs obtained with WFC shown in FIGS. 13(d) through 13(i), that the effects of misfocus may be virtually eliminated with the inclusion of WFC in the optical system.

(A) (B) (C)

FIG. 14. (A) Image of a set of microscopic bubbles with a traditional microscope; (B) the same image with a WFC microscope; and (C) the same WFC microscope image after post- processing.

In some cases, it may not be necessary to perform post-processing of the WFC image to obtain the desired information. For example, if the goal is simply to determine the presence, location and number of the bubbles of FIG. 14, the processed image shown in FIG. 14(C) may not be needed. In the example shown in FIGS. 14(A) through 14(C), the image obtained with a traditional microscope shown in FIG. 14(A) may not yield the required information, since some of the bubbles are not imaged in sufficient resolution to be counted. However, the unprocessed, WFC image shown in FIG. 14(B), while not giving as clear an image as the post-processed, WFC image of FIG. 14(C), may provide all of the information required for a particular application.

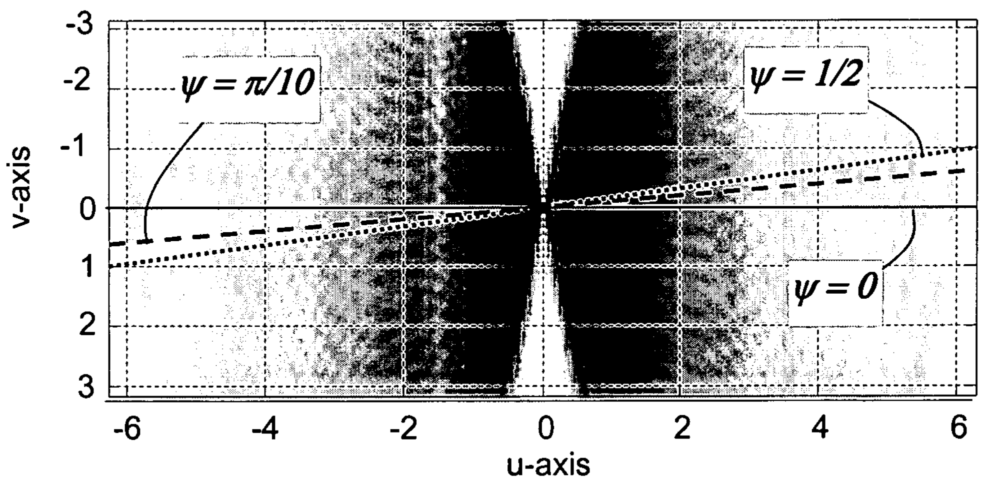

FIG. 15. AF of a WFC, cubic phase system.

FIG. 15 shows the AF for a one-dimensional, WFC imaging system including the cubic phase function shown in FIG. 12. In comparing FIG. 15 with the previously discussed FIG. 4 showing the AF for the unmodified, traditional imaging system, it may be noted that the darker, higher intensity region extends over a larger angle away from the horizontal, v = 0 axis. That is, for any given, non-zero value of the spatial frequency parameter u, the main lobe (i.e., the large, gray region above and below the $v = 0$ line) of the AF of the WFC, cubic phase system is very

broad in the v-direction in comparison to the unmodified, traditional imaging system such that the WFC imaging system including the added cubic phase exhibits a larger depth of field.

Continuing to refer to FIG. 15, as explained earlier, darker shades in the ambiguity function plot indicate higher magnitude of the ambiguity function. Upon examination of FIGS. 4 and 7, it may be seen that, for a line traversing the ambiguity function corresponding to non-zero values of misfocus ψ, the magnitude distribution of the ambiguity function for an unmodified, traditional imaging system and the stopped down system are still quite narrow compared to the AF shown in FIG. 15 because most of the power in the ambiguity function plots is concentrated along the v = 0 axis. In contrast, as the power of the ambiguity function for a WFC imaging system is more uniformly distributed, the magnitude distribution of the ambiguity function for the WFC imaging system is broader along any given line traversing the ambiguity function for non-zero values of misfocus ψ without reduction in spatial resolution. That is, while the main lobe, or the region of high magnitude (i.e., the darker region), of the AF of the unmodified, traditional imaging system is concentrated along the v = 0 axis, the main lobe of the AF of the WFC imaging system is spread throughout a larger portion of the entire AF plot over a larger range of misfocus parameter ψ.

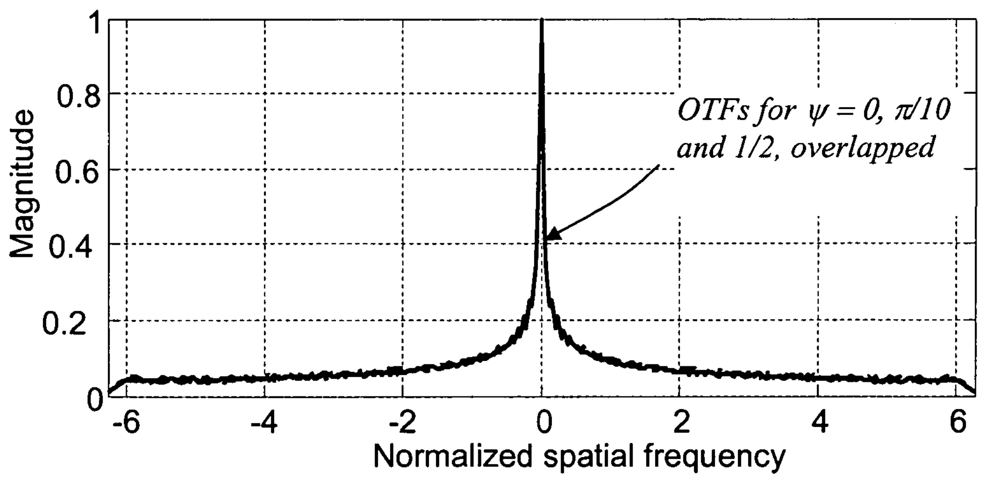

FIG. 16. OTFs of a WFC, cubic phase system for three values of misfocus.

The traces through the AF shown in FIG. 15 for the WFC imaging system for three different values of misfocus, namely for $\psi = 0$, $\pi/10$ and ½, are shown in FIG. 16. As may be

seen in FIG. 16, the WFC imaging system exhibits substantially the same OTF for these values of misfocus (note that the curves in FIG. 16 corresponding to $\psi = 0$ and ½ are the same curves as shown in Fig. 10 and Fig. 12 of the present application.) In other words, the OTF is essentially constant over this range of misfocus, and, the WFC system is invariant to misfocus over the normalized spatial frequency range of $\pm 2\pi$. Also, since the OTFs shown in FIG. 16 correspond to cross sections of the AF shown in FIG. 15, these OTFs illustrate the broadening of the main lobe of the AF, as the central non-zero portions of the OTFs (around the $u = 0$ axis and corresponding to cross sections of the main lobe of the AF) now extend over the normalized spatial frequency range of $\pm 2\pi$ for even non-zero values of misfocus parameter ψ. That is, in comparing the OTFs of the WFC imaging system as shown in FIG. 16 with the OTFs of the unmodified, traditional imaging system as shown in FIG. 3, for example, it may be seen that the central non-zero portion of the OTFs (corresponding to cross sections of the main lobe of the AF) for non-zero values of misfocus are significantly broader in the WFC system as compared to the unmodified, traditional imaging system.

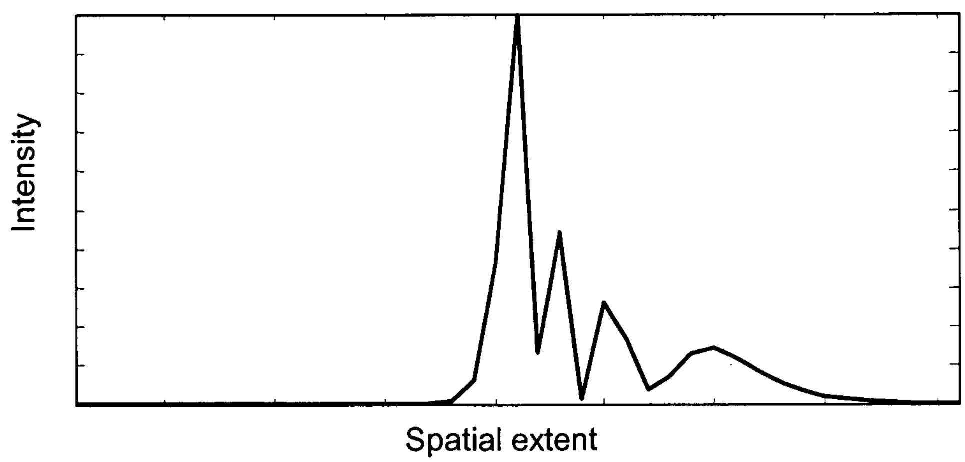

FIG. 17. PSF of a WFC, cubic phase system for zero misfocus ($\psi = 0$).

FIG. 17 shows the PSF of a WFC, cubic phase system (without post-processing) for zero misfocus ($\psi = 0$). FIG. 17 corresponds to Fig. 20 of the application as filed, except for the choice of horizontal and vertical scales, and resolution of the data plotted. In comparing the PSF

shown in FIG. 17 with that of the unmodified, traditional imaging system (FIG. 5), the stopped down system (FIG. 8(A)) and the stepped phase system (FIG. 10(A)), it may be observed that the functional form of the PSF of the WFC system is quite different from those of the unmodified, traditional imaging system, the stopped down system and the stepped phase system. That is, the PSF of the WFC system, without post-processing, is more asymmetric in comparison to *sinc*-squared forms of the PSFs of the earlier discussed systems. In other words, the functional form of the PSFs in a WFC imaging system is different from the functional form (i.e., *sinc*-squared) common to the earlier discussed unmodified, traditional imaging system, the stopped down system and the stepped phase system. In fact, after post-processing, the PSFs of a WFC imaging system remain consistent for a range wide misfocus values, as indicated in Figures 21-23 of the application as filed.

Another way to compare the PSF of the WFC system with those of the traditional imaging system is to compare the images of point sources produced by the different systems for different values of misfocus. The images of point sources, as shown in FIGS. 13(a)-13(i), yield a visual comparison of the PSFs of the unmodified, traditional imaging system with the PSFs of the WFC system, without and with post-processing. For example, it may be seen that the images of point sources of the unmodified, traditional microscope (as shown in FIGS. 13(a)-13(c)) appear more distorted with increased misfocus. That is, the image of the point source becomes increasingly more distorted as the system is brought further out of focus from the in-focus image of FIG. 13(a) to the more out-of-focus images of FIGS. 13(b) and 13(c). However, the WFC system, without post-processing, (as shown in FIGS. 13(d)-13(f)) produces images of the point source that are asymmetric in a consistent manner regardless of misfocus; that is, FIGS. 13(d)-13(f) are all asymmetric but visually similar. Consequently, a single digital filter, generated with *a priori* knowledge of the optical system and phase function but without knowledge of the misfocus parameter value, may be used to restore all of the WFC images in FIGS. 13(d)-13(f) to images of the point source, as shown in FIGS. 13(g)-13(i). Such recovery of the point source images regardless of misfocus would not be possible with any one of the unmodified, traditional imaging, the stopped down, and the stepped phase systems.

Detailed Responses to Examiner's Statements, Objections and Rejections in Office Action of 8 July 2005

The following paragraphs follow the order of the paragraphs in the Office Action mailed 8 July 2005 in this application.

Remark

Applicants acknowledge Examiner's entry of Applicants' amendment of 5 May 2005.

1-2. Election/Restrictions

The Examiner has indicated that previously amended claims 1-3 and 9-10 are directed to an invention that is independent or distinct from the invention originally claimed. While Applicants traverse the Examiner's categorization of claims 1-3 and 9-10 as distinct from claims 7-8, claims 1-3 and 9-10 are cancelled in the present paper in an effort to further the prosecution of the present application. Applicants may prosecute the cancelled claims in a continuation or divisional application of the present patent application.

3. Drawings

Applicants acknowledge with appreciation the Examiner's withdrawal of previous objections to the drawings in response to the Applicants' Amendment and Response of 5 May 2005.

4. Previous 35 U.S.C. §112 first paragraph rejections

Applicants gratefully note the Examiner's withdrawal of previous rejections of claims 7-8 and 11 under 35 U.S.C. §112, first paragraph, in response to the Applicants' Amendment and Response of 5 May 2005.

5. Information Disclosure Statement

The Examiner has repeated that "The information disclosure statement filed January 16, 2004, contains a list of more than 150 references yet does not include a concise explanation of the relevance. It has been placed in the application file, but the information referred to therein has not been considered." Office Action, page 3 Applicants hereby refer to, and reiterate, each

of the statements and arguments that were included in Applicants' Amendment and Response of 5 May 2005 under the heading "Information Disclosure Statement."

As noted above, during the Interview of December 6, 2005, the Examiner requested that Applicants provide a categorized list of all of the cited art. The following table therefore lists all art cited in previously filed Information Disclosure Statements, and divides such art into categories, as requested by Examiner Chang. This table does not constitute a search conducted by Applicants and neither is it an acknowledgement of prior art.

Non-Patent Publications

	TITLE	FIRST AUTHOR	PUBLICATION	VOL	NO	PAGES	DATE	CATEGORY
1	Misfocus tolerance seen by simple inspection of the ambiguity function	H. Bartelt	Applied Optics	23	16	p. 2693-2696	8/15/1984	Analysis of optical systems
2	Ambiguity function as a design tool for high focal depth	J. Ojeda-Castañeda	Applied Optics	27	4	p.790-795	2/15/1988	Analysis of optical systems
3	Conoscopic holography. I. Basic principles and physical basis	Gabriel Y. Sirat	Journal of the Optical Society of America A	9	1	p. 70—90	Jan-92	Analysis of optical systems
4	Principle of equivalence between scanning and conventional optical imaging systems	Dorian Kernisch	Journal of the Optical Society of America	67	10	p. 1357-1360	Oct-77	Analysis of optical systems
5	Preferred Sharpness of Photographic Color Images	Souichi Kubo	Journal of Imaging Science	29	6	p.213-215	Nov/Dec 1985	Analysis of optical systems
6	Aberration Curves in Lens Design	Donald C. O'Shea	Book - Chapter 33			p. 33.1-33.5	1995	Analysis of optical systems
7	Binary Optics	Wilfrid B. Veldkamp	Scientific American	266	5	p. 50-55	May-92	Diffractive optics
8	Spatial filter for increasing the depth of focus	J. Ojeda-Castañeda	Optics Letters	10	11	p. 520-522	Nov-85	Filter
9	Apodization of annular apertures: Strehl ratio	J. Ojeda-Castañeda	Applied Optics	27	24	p. 5140-5145	12/15/1988	Filter
10	Annular apodizers for low sensitivity to defocus and to spherical aberration	J. Ojeda-Castañeda	Optics Letters	11	8	p. 487-489	Aug-86	Filter

11	Arbitrarily high focal depth with a quasioptimum real and positive transmittance apodizer	J. Ojeda-Castañeda	Applied Optics	28	13	p. 2666-2670	7/1/1989	Filter
12	Arbitrarily high focal depth with finite apertures	J. Ojeda-Castañeda	Optics Letters	13	3	p. 183-185	Mar-88	Filter
13	Imaging with Fresnel zone pupil masks: extended depth of field	Guy Indebetouw	Applied Optics	23	23	p. 4299-4302	12/1/1984	Filter
14	Use of Annular Apertures to Increase Focal Depth	W. T. Welford	Journal of the Optical Society of America	50	8	p. 749-753	Aug-60	Filter
15	Imaging properties of defocused partitional pupils	Chanin Varamit	Journal of the Optical Society of America A	2	6	p. 799-802	Jun-85	Filter
16	Phase-shifting apodizers for increasing focal depth	Haifeng Wang	Applied Optics	41	25	p. 5263-5266	9/1/2002	Filter
17	High focal depth with a pure-phase apodizer	Haifeng Wang	Applied Optics	40	31	p. 5658-5662	11/1/2001	Filter
18	A Logarithmic Phase Filter to Extend the Depth of Field of Incoherent Hybrid Imaging Systems	Sherif, S.S.	SPIE Proceedings	4471		p.272-280	Nov-01	Filter
19	Zone plate for arbitrarily high focal depth	J. Ojeda-Castañeda	Applied Optics	29	7	p. 994-996	3/1/1990	Filter
20	Improvement in the OTF of a Defocused Optical System Through the Use of Shaded Apertures	M. Mino	Applied Optics	10	10	p. 2219-2225	10/1/1971	Filter
21	Color dependent optical prefilter for the suppression of aliasing artifacts	John E. Greivenkamp	Applied Optics	29	5	p. 676-684	2/10/1990	Filter
22	High focal depth by quasibifocus	J. Ojeda-Castañeda	Applied Optics	27	20	p. 4163-4165	10/15/1988	Increasing depth of focus
23	Quantitative DIC Microscopy using a Geometric Phase Shifter	Cogswell, C.J.	SPIE Proceedings	2984		p. 72-81	Apr-97	Microscope

24	Confocal Differential Interference Contrast (DIC) Microscopy: including a theoretical analysis of conventional and confocal DIC imaging	Cogswell, C.J.	Journal of Microscopy	165	1	p. 81-101	Jan-92	Microscope
25	An optical coherence microscope with enhance resolving power in thick tissue	J. M. Schmitt	Optics Communications	142		p. 203-207	Year 1997	Microscope
26	Polarization contrast imaging of thin films in scanning microscopy	S.V. Shatalin	Optics Communications	116		p. 291-299	5/1/1995	Microscope
27	Geometrical cross-sectional imaging by a heterodyne wavelength-scanning interference confocal microscope	Takashi Fukano	Optics Letters	25	8	p.548-550	4/15/2000	Microscope
28	Electronic imaging using a logarithmic asphere	Wanli Chi	Optics Letters	26	12	p. 875-877	6/15/2001	Optical system with signal processing
29	Three-dimensional tomography using a cubic-phase plate extended depth-of-field system	Marks, D.L.	Optics Letters	24	4	p. 253-255	2/15/1999	Optical system with signal processing
30	Extended Depth of Field and Aberration Control for Inexpensive Digital Microscope Systems	Tucker, S.C.	Optics Express	4	11	p. 467-474	5/24/1999	Optical system with signal processing
31	Single-lens single-image incoherent passive-ranging systems	Dowski, E.R.	Applied Optics	33	29	p. 6762-6773	10/10/1994	Optical system with signal processing
32	Image Gathering and Processing for Enhanced Resolution	Cathey, W.T.	Journal of the Optical Society of America A	1	3	p. 241-250	Mar-84	Optical system with signal processing
33	Broadband Behavior of an Optical-Digital Focus-invariant System	Van der Gracht J.	Optics Letters	21	13	p. 919-921	7/1/1996	Optical system with signal processing

34	A method to increase the depth of focus by two step image processing	G. Hausler	Optics Communications	6	1	p. 28-42	Sep-72	Optical system with signal processing
35	Partially coherent image processing by laser scanning	Dorian Kermisch	Journal of the Optical Society of America	65	8	p. 887-891	8/1/1975	Optical system with signal processing
36	Image processing for extended depth of field	R. J. Pieper	Applied Optics	22	10	p. 1449-1453	5/15/1983	Optical system with signal processing
37	Passive ranging through wave-front coding: information and application	Johnson, G.E.	Applied Optics	39	11	p.1700-1710	4/10/2000	Optical system with signal processing
38	Extended Depth of Field Through Wave-front Coding	Dowski, E.R. Jr	Applied Optics	34	11	p. 1859	4/10/1995	Optical system with signal processing
39	Control of Chromatic Focal Shift Through Wave-front Coding	Wach, H.B.	Applied Optics	37	23	p. 5359-5367	8/10/1998	Optical system with signal processing
40	High focal depth by apodization and digital restoration	J. Ojeda-Castañeda	Applied Optics	27	12	p. 2583-2586	6/15/1988	Optical system with signal processing
41	Coherent Processing and Depth of Focus of Annular Aperture Imagery	J. T. McCrickerd	Applied Optics	10	10	p. 2226-2230	Oct-71	Optical system with signal processing
42	Nonmechanical microscanning using optical space-fed phased arrays	Kenneth J. Barnard	Optical Engineering	33	9	p. 3063-3071	Sep-94	Optical system with signal processing
43	Imaging System with Range to Each Pixel	Cathey, W.T.	Journal of the Optical Society of America A	3	9	p. 1537-1542	Sep-86	Optical system with signal processing
44	Axi-vision camera: a three-dimension camera	Masahiro Kawakita	Proceedings of SPIE	3958		p. 61-70	Year 2000	Optical system with signal processing

45	Surface Profile Measurement Using Color Fringe Projection	Clarence Wust	Machine Vision and Applications	4		p. 193-203	Year 1991	Optical system with signal processing
46	Sub-pixel shift with Fourier transform to achieve efficient and high quality image interpolation	Qin-Sheng Chen	SPIE Conf. on Image Processing	3661		p. 728-736	Feb-99	Optical system with signal processing
47	High-resolution image reconstruction from multiple low-resolution images	H. Wei	Image Processing and its Applications, 7th International Conference , IEE, Pub. No. 465	2		p. 596-600	7/13/1999 - 7/15/1999	Optical system with signal processing
48	Imaging with Expanded Depth of Focus	Gerd Hausler	Zeiss Inform, Cberkuchen	29	98	p. 9-13	1986/1987	Optical system with signal processing
49	ISR received in PCT/US01/26126 (Individual citations are listed separately elsewhere in this list)	Siebert, J. (Officer)						

U.S. Patent Publications

	TITLE	INVENTOR	ASSIGNEE	PATENT NO.	PATENT DATE	CATEGORY
1	Accoustic Beam Former	Whitehouse, Harper John	USA Secretary of the Navy	3,873,958	3/25/1975	Array filter
2	Method and Apparatus For Obtaining a Composite Field Response to a Variable Source Array using Weighting Coefficients	Kahn, Twassul A., John W. Kiowski	Geosource Inc.	4,276,620	6/30/1981	Array filter
3	Phase Noise Filter - Photography/Photolithography	Sayanagi, Kazuo	Canon Camera Company	2,959,105	11/8/1960	Filter
4	Variable Backround Intensity Apparatus For Imaging Systems	Hoffman, Robert		4,062,619	12/13/1977	Filter

5	Image Processing System using Incoherent Radiation and Spatial Filter Hologram	Ward, Joseph E.	Minnesota Mining and Manufacturing Company	4,082,431	4/4/1978	Filter
6	Filter Rotator for Coherent Optical Correlation System	B.W. Joseph, A.D.Gara	General Motors Corporation	4,174,885	11/20/1979	Filter
7	Optical Filter Suitable for Portrait Photography	Kubo, Souchi Okano, Yukio	Minolta Camera Kabushiki Kaisha	4,480,896	11/6/1984	Filter
8	Optical Spatial Frequency Filter	Greivenkamp Jr., John	Eastman Kodak Company	4,575,193	3/11/1986	Filter
9	Anti-Aliasing Optical System with Pyramidal Transparent Structure	Plummer, William T.	Polaroid Corporation	4,989,959	2/5/1991	Filter
10	Optical Phase-only Spatial Filter	Kelly, Shawn L.		5,142,413	8/25/1992	Filter
11	Wavelength Selective Phase Grating Optical Low-Pass Filter	Okayama, Hiroaki, S. Ono	Matsushita Electric Industrial Co., Ltd.	5,280,388	1/18/1994	Filter
12	Optical Fiber Filter for Reducing Artifacts in Imaging Apparatus	Jackson, Todd A., R.H. Hibbard	Eastman Kodak Company	5,299,275	3/29/1994	Filter
13	Optical Spatial Filter	Kelly, Shawn L.		5,337,181	8/9/1994	Filter
14	Aspherical Blur Filter for Reducing Artifacts in Imaging Apparatus	Jackson, T.A., R.H. Hibbard	Eastman Kodak Company	5,438,366	8/1/1995	Filter
15	Optical Low Pass Filter	Konno, Mitsujiro, Katsuya Ono, Yoshiharu Takasugi, Shinya Matsumoto, Kimihiko Nishioka	Olympus Optical Co., Ltd.	5,555,129	9/10/1996	Filter
16	Camera Apparatus Having an Optical Low-Pass Filter	Hamano, Hiroyuki	Canon Kabushiki Kaisha	5,568,197	10/22/1996	Filter

17	Optical Low-Pass Filter and Optical Apparatus Having the Same	Okuyama, Atsushi Kobayashi, Shuichi Wada, Ken	Canon Kabushiki Kaisha	6,144,493	2/20/1997	Filter
18	Display Panel and Display Device Using the Same	Takahara, H., S. Shannohe	Matsushita Electric Industrial Co., Ltd.	6,218,679	4/17/2001	Filter
19	Reflection Type LCD Pixel Having Outer Low Reflectivity Region Surrounding High Reflectivity Region Upon Which Microlens Light is Focussed	Inoue, S., K. Kurematsu, O. Koyama	Canon Kabushiki Kaisha	6,172,723	1/9/2001	Microlens array
20	Edge Enhancement of Phase Phenomena	Ellis, Gordon W.	Research Corporation	4,255,014	3/10/1981	Microscope
21	Confocal Sanning Laser Microscope having no Moving Parts	Goldstein, Seth R.	USA Secretary of the Department of Health and Human Services	4,827,125	5/2/1989	Microscope
22	Differential Interference Microscope	Hayashi, Shinichi	Olympus Optical Co., Ltd.	4,964,707	10/23/1990	Microscope
23	Tandem Linear Scanning Confocal Imaging System with Focal Volumes at Different Heights	Kerstens, P.J., R. Mandeville, F.Y. Wu	IBM	5,248,876	9/28/1993	Microscope
24	Differential Interference Microscope Apparatus and an Observing Method Using the same Apparatus	Otaki, Tatsuro Kawahito, Takashi	Nikon Corporation	5,572,359	11/5/1996	Microscope
25	Phase Contrast Microscope	Ishiwata, Hiroshi Nagano, Chikara	Olympus Optical Co., Ltd.	5,751,475	5/12/1998	Microscope
26	Optical Microscope Which has Optical Modulation Elements	Takaoka, Hideyuki	Olympus Optical Co., Ltd.	5,969,853	10/19/1999	Microscope

27	Microscope Apparatus	Ishiwata, Hiroshi Yatagai, Toyohiko Itoh, Masahide	Olympus Optical Co., Ltd.	5,969,855	10/19/1999	Microscope
28	Differential Interference Microscope	Otaki, Kumiko	Nikon Corporation	6,034,814	3/7/2000	Microscope
29	Differential Interference Contrast Microscope and Microscopic Image Processing System using the same	Kusaka, Kenichi	Olympus Optical Co., Ltd.	6,128,127	10/3/2000	Microscope
30	Conventional and Confocal Multi-spot Scanning Optical Microscope	Krantz, Matthias C.	KLA-Tencor Corporation	6,248,988	6/19/2001	Microscope
31	Light Imaging Microscope Having Spatially Resolved Images	Garner, Harold R. Schultz, Roger A.	The University of Texas System Board of Regents	6,337,472	1/8/2002	Microscope
32	Multiple-Invariant Space-Variant Optical Processing	Casasent, David P. Psaltis, Demetri	USA Secretary of the Navy	4,308,521	12/29/1981	Optical processor
33	Infrared Ranging System	Westover, Thomas A.	Servo Corporation of America	3,054,898	9/18/1962	Optical system
34	Apparatus for No-Contact Measurement having a Multi-Colored Grating	Hartmann, Horst Stankewitz, Hans-Werner	Ernst Leitz GmbH	3,856,400	12/24/1974	Optical system
35	3-Dimensional Camera Device	Marks, Alvin M. Marks, Mortimer		4,178,090	12/11/1979	Optical system
36	Optical System Phase Error Compensator	Klooster Jr., Alex	Environmenta l Research Institute of Michigan	4,275,454	6/23/1981	Optical system
37	Non-contact Measurement of Surface Profile	Mundy, Joseph L., G.B. Porter III, T.M. Cipolla	General Electric Company	4,349,277	9/14/1982	Optical system with signal processing

38	Multi-Detector Intensity Interferometer and Method for Processing Incoherent Radiation Signals	Fontana, Peter	State of Oregon	4,466,067	8/14/1984	Optical system with signal processing
39	Stereoscopic Vision System	Kidode, Masatsuga Kuno, Yoshinori	Tokyo Shibaura Denki Kabushiki Kaisha	4,573,191	2/25/1986	Optical system with signal processing
40	Electro-Optical Ranging Apparatus Having Scanning Circuitry and Servoloop Processor for Resolving Separation Of images on Photoelectric Detector Arrays	Jones, Phillip Jones, William R. Storey, Moorfield	The Boeing Company	4,589,770	5/20/1986	Optical system with signal processing
41	Method for Increasing the Resolution of a Color Television Camera with Three Mutually-Shifted Solid-State Image Sensors	Wolf-Peter Buchwald	Robert Bosch GmbH	4,725,881	2/16/1988	Optical system with signal processing
42	Passive Ranging Method and Apparatus	Kaplan, Albert		4,734,702	3/29/1988	Optical system with signal processing
43	Extended-Range Moire Contouring	Greivenkamp Jr., John	Eastman Kodak Company	4,794,550	12/27/1988	Optical system with signal processing
44	Optical Method an Apparatus for Determining Three-Dimensional Changes in Facial Contours	Desjardins, Paul J. Dunn, Stanley M. Milles, Maano	University of Medicine & Dentistry of New Jersey, and Rutgers University	4,825,263	4/25/1989	Optical system with signal processing
45	Pattern Recognition Process	Steinpichler, Deitmar Osterreicher, Gerhard W.		4,843,631	6/27/1989	Optical system with signal processing
46	Multidimensional Range Mapping with Pattern Projection and Cross Correlation	Girod, Bernd	Massachusetts Institute of Technology	5,003,166	3/26/1991	Optical system with signal processing
47	Optical Ranging Apparatus	Adelson, Edward H.	Massachusetts Institute of Technology	5,076,687	12/31/1991	Optical system with signal processing

48	Method and Apparatus for Measuring a Three-Dimensional Curved Surface Shape	Uesugi, Mitsuaki Inomata, Masaichi Komine, Isamu	NKK Corporation	5,102,223	4/7/1992	Optical system with signal processing
49	Inertial Navigation Sensor Integrated Obstacle Detection System	Bhanu, Bir Roberts, Barry A.	Honeywell, Inc.	5,128,874	7/7/1992	Optical system with signal processing
50	Device for Measuring Distances using an Optical Element of Large Chromatic Aberration	Strater, Hans-Dieter Gross, Daniel Jauch, Karl M.	Battelle-Institute e V.	5,165,063	11/17/1992	Optical system with signal processing
51	Computational Methods and Electronic Camera Apparatus for Determining Distance of Objects, Rapid Autofocusing, and Obtaining Improved Focus Images	Subbarao, Muralidhara	The Research Foundation of State University of New York	5,193,124	3/9/1993	Optical system with signal processing
52	Full Aperture Image Synthesis Using Rotating Strip Aperature Image Measurements	Rafanelli, Gerard L. Rehfield, Mark J.	Hughes Aircraft Company	5,243,351		Optical system with signal processing
53	Imaging Optical System Having a Moire Elimination Effect	Takasugi, Yoshiharu, A. Hasegawa	Olympus Optical Co. Ltd	5,270,825	12/14/1993	Optical system with signal processing
54	Image Compression Method and Apparatus Employing Principal Component Analysis	Kirk, Richard A.	Crosfield Electronics Limited	5,301,241	4/5/1994	Optical system with signal processing
55	Optical Image Defocus Correction	Seachman, Ned	Xerox Corporation	5,307,175	4/26/1994	Optical system with signal processing
56	Distributed Aperture Imaging and Tracking System	Hale, Robert A. Nathanson, Harvey C. Hazlett, Joel F.	Westinghouse Electric Corp	5,317,394	5/31/1994	Optical system with signal processing
57	Aberration Correction Method and Aberration Correction Apparatus	Chen, Jun. G. Lai, K. Ishizuka, A. Tonomura	Research Development Corporation of Japan	5,426,521	6/20/1995	Optical system with signal processing

58	Method for Improving the Resolution of Three CCD Camera and Apparatus Thereof	Lee, Hyo S.	Samsung Electronics	5,442,394	8/15/1995	Optical system with signal processing
59	Electronic Image Pickup Apparatus Equipped with Means for Eliminating Moire	Katsuya, Ono Hasegawa, Akira	Olympus Optical Co., Ltd.	5,444,574	8/22/1995	Optical system with signal processing
60	Method and Apparatus for Acquiring Images Using a CCD Detector Array and No Transverse Scanner	Swanson, E.A.	MIT	5,465,147	11/7/1995	Optical system with signal processing
61	Range Estimation Apparatus and Method	W.T. Cathey, Jr, E.R. Dowski Jr	The Regents	5,521,695	5/28/1996	Optical system with signal processing
62	Image Pickup Apparatus with Horizontal Line Interpolation Functioin Having Three Image Pickup Units Shifted in Vertical Phase from One Another	Kusaka, Hiroya, T. Sakaguchi, M. Nakayama	Matsushita Electric Industrial Co.	5,532,742	7/2/1996	Optical system with signal processing
63	Multiple Focus Optical System for Data Reading Applications	Reddersen, B.R., T.C. Arends	Spectra-Physics Scanning Systems, Inc.	5,565,668	10/15/1996	Optical system with signal processing
64	Projection Exposure Apparatus	Shiraishi, Naomasa	Nikon Corporation	5,610,684	3/11/1997	Optical system with signal processing
65	Imaging Apparatus Including Offset Pixels for Generating Vertical High Frequency Componenet	Kinoshita, Kosuke, T. Shinozaki, T. Tsushima, M. Yoshida, H. Kitamura, T. Suwa	Victor Company of Japan, Ltd.	5,640,206	6/17/1997	Optical system with signal processing
66	High Fidelity Optical System for Electronic Imaging	S.L. Kelly		5,706,139	1/6/1998	Optical system with signal processing
67	Extended Depth of Field Optical Systems	W.T. Cathey Jr, E.R. Dowski Jr	The Regents	5,748,371	5/5/1998	Optical system with signal processing

68	Anti-Aliasing Apparatus and Methods for Optical Imaging	W.T. Cathey Jr, E.R. Dowski Jr	University Technology Corp.	6,021,005	2/1/2000	Optical system with signal processing
69	Endocscope System Provided with Low-Pass Filter for Moire Removal	Nishioka, K., N. Hasegawa, K. Ono, Y. Tatsuno	Olympus Optical Co., Ltd.	6,025,873	2/15/2000	Optical system with signal processing
69	Optical Interferometer Employing Multiple Detectors to Detect Spatially Distorted Wavefront in Imaging of Scattering Media	Chan, Kinpui Satori, Koji	Biophotonics Information Laboratories Ltd.	6,037,579	3/14/2000	Optical system with signal processing
70	Apparatus and Methods for Extending Depth of Field in Image Projection Systems	W.T. Cathey Jr	Univ. Tech. Corp.	6,069,738	5/30/2000	Optical system with signal processing
71	Optical System with Two-Stage Aberration Correction	Chen, Chungte W.	Raytheon Company	6,091,548	7/18/2000	Optical system with signal processing
72	Apparatus and Method for Reducing Imaging Errors in Imaging Systems Having an Extended Depth of Field	Hammond, C.M. Jr,	Welch Allyn Inc.	6,097,856	8/1/2000	Optical system with signal processing
73	Optical Confocal Device having a Common Light Directing Means	Hang, Zhijiang Lazarev, Victor Webb, Robert H.		6,121,603	9/19/2000	Optical system with signal processing
74	Three Channel Acousto-Optical Devices	Raj, Kannan	Intel Corporation	6,172,799	1/9/2001	Optical system with signal processing
75	Polarization Conversion System, Illumination System, and Projector	Itoh, Yoshitaka	Seiko Epson Corporation	6,208,451	3/27/2001	Optical system with signal processing
76	Method and Apparatus for Driving an Active Matrix Display Panel	Takahara, Hiroshi	Matsushita Electric Industrial Co., Ltd.	6,219,113	4/17/2001	Optical system with signal processing

77	Liquid Crystal Display	Crossland, William A. Davey, Anthony B.	The Secretary of State for Defence in Her Britannic Majesty's Government of the United Kingdom of Great Britain and Northern Ireland	6,285,345	9/4/2001	Optical system with signal processing
78	Micro-Scanning Multislit ConFocal Image Acquisition Apparatus	Ishihara, Mitsuhiro	Takaoka Electric Mfg. Co. Ltd.	6,288,382	9/11/2001	Optical system with signal processing
79	Two-Element Variable-Power Spherical Lens	Alvarez, Luis W.	Optical Research and Development Corporation	3,305,294	2/21/1967	Variable Lens
80	Variable Power, Analytical Function, Optical Component-Pair of Laterally Adjustable Plates Having Shaped Sufaces	Baker, James G.	Polaroid Corporation	3,583,790	6/8/1971	Variable Lens
81	Continuously Variable Contact Lens	Nuchman, Benjamin Whang, Sang Y.		4,580,882	4/8/1986	Variable Lens
82	Artificial Eye Lenses	Freeman, Michael	Pilkington P.E. Limited	4,642,112	2/10/1987	Variable Lens
83	Analytic Function Optical Component	Baker, James G. Plummer, William T.	Polaroid Corporation	4,650,292	3/17/1987	Variable Lens
84	Ophthalmic Lenses with Diffractive Power	Freeman, Michael H.	Pilkington P.E. Limited, UK	4,655,565	4/7/1987	Variable Lens
85	Wide Depth of Focus Intraocular and Contact Lenses	Oksman, Henry C., J. Eisner		5,260,727	11/9/1993	Variable Lens
86	Method of Making Intraocular Lenses with Injectable Collagen-based Compositions	Kelman, Charles D., D. P. DeVore	Autogenesis Technologies, Inc.	5,476,515	12/19/1995	Variable Lens

87	Zoom Lens With Short Back Focal Length	Betensky, Ellis I., MH Kreitzer, Jacob Moskovich		4,936,661	6/26/1990	Zoom lens
88	Zoom Lens System for use in a Compact Camera	Estelle, Lee R.	Eastman Kodak Company	5,270,861	12/14/1993	Zoom lens
89	Compact Zoom Lens Having A Weak Front Lens Group	Estelle, Lee R.	Eastman Kodak Company	5,270,867	12/14/1993	Zoom lens
90	Two Element Plastic Zoom Camera Lens	Estelle, L.R., A.E. Lewis	Eastman Kodak Company	5,473,473	12/5/1995	Zoom lens

Foreign Patent Documents

	TITLE	ASIGNEE	INVENTOR	PATENT NO.	PATENT DATE	COUNT RY	CATEGORY
1	Optical Head	Toshiba	Genichi, Hatagoshi	JP60247611	12/7/1985	JP	Diffractive optics
2	Wavelength-selective phase-type optical low-antialiasing filter and fabrication methods	Eastman Kodak Company	J.F. Revelli Jr, A.C.G. Nutt, E.T. Prince, J. Gasper, S.A. Wilson, T.A. Jackson	EP 0 759 573 A2	2/26/1997	EP	Filter
3	Wavelength-selective phasegrating optical low-pass filter	Matsushita Electric Industrial Co, Ltd	Hiroaki Okayama, Osaka Hirakata-shi	EP 0 531 926 B1	12/16/1998	EP	Filter
4	Video device utilizing a two-dimensional diffraction grating	Kuraray Co., Ltd	Ikuo Ohnishi, Okayama-ken Kurashiki-shi	EP 0 618 473 A2	10/5/1994	EP	Filter
5	Two-dimensional optical low-pass filter	Matsushita Electric Industrial Co, Ltd	Hiroaki Okayama, Osaka-fu Hirakata-shi	EP 0 584769 B1	1/28/1998	EP	Filter
6	Optical low-pass filter and optical apparatus having the same	Canon Kabushiki Kaisha, Tokyo	Atsushi Okuyama, Shuichi Kobayashi, Ken Wada	EP 0 791 846 A2	8/27/1997	EP	Filter

7	Concentric ring single vision lens designs	Johnson & Johnson Vision Products	J. H. Roffman, E.V. Menezes	EP 0 742 466 A2	11/13/1996	EP	Lens
8	System and Method for Increasing the Depth of Focus of the Human Eye	Boston Innovative Optics, Inc.	David Miller, Ernesto Blanco	WO 00/52516	9/8/2000	PCT	Lens
9	Solid-state image sensing apparatus, control method therefore, basic layout of photoelectric conversion cell and storage medium	Canon Kabushiki Kaisha	Kenichi Kondo, Yukichi Niwa, Shinji Sakai, Yoshihiro Saga	EP 0 981 245 A2	2/23/2000	EP	Optical system with signal processing
10	Optical spatial filtering with electronic image compression	Motion Media Technology Limited	Kennith Neville Burgin	GB 2 278 750 A	12/7/1994	UK	Optical system with signal processing

Accordingly, we now request that the Examiner consider the art cited in connection with this application in prior information disclosure statements.

6. Claim Objections

The Examiner objected to claim 11, stating:

> The symbol "Ψ" recited in claim 11 is confusing and indefinite since the claim fails to define what does this symbol stand for. Furthermore, it is not clear what is considered to be the "range of Ψ". It is not clear if this is referred to a spatial frequency or not. The scope of the claim therefore is confusing and not clear.

In an effort to address the Examiner's objections, claim 11 has been amended to clarify that the symbol "ψ" stands for a misfocus parameter, as clearly defined in paragraph **[0075]** of the specification as filed. Specifically, claim 11 has been amended to recite an imaging system including:

> at least one lens, an optical mask and a detector that cooperate to image light from an object to form a stored image, which lens is characterized by at least a length L, a focal length f, a front principal plane and a rear principal plane, and which light is characterized by at least phase and a wavelength λ, the optical

> mask modifying the phase such that a main lobe of the ambiguity function is broader for a given range of ψ at a given value of u, and the PSF has a functionally different form, in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the imaging system without the optical mask for that given range of the misfocus parameter ψ, defined by the equation:
>
> $$\psi = \frac{L^2}{4\pi\lambda}\left(\frac{1}{f} - \frac{1}{d_o} - \frac{1}{d_i}\right),$$
>
> where d_o is a distance from the object to the front principal plane and d_i is a distance from the rear principal plane to the detector.

Therefore, it is respectfully submitted that claim 11, as amended, overcomes the Examiner's objections, and withdrawal of the Examiner's objections regarding claim 11 is respectfully requested.

7. – 8. Claim Rejections - 35 U.S.C. §102(b)

The Examiner rejected claim 7 under 35 U.S.C. §102(b) as being anticipated by U.S. Patent No. 4,480,896 to Kubo et al. (hereinafter, "Kubo"). In particular, the Examiner states:

> Kubo et al further teaches that the optical mask also modulating the wavefront of the light from the sharp objective lens to make the imaging system has [sic] a *soft focus effect* which implicitly means that it creates an extend [sic] of the depth of focus that is larger than the focus of the imaging system without the optical mask, (please see column 1-2). **This reference has therefore anticipated the claims.**

Applicants respectfully disagree and traverse this rejection.

Initially addressing the teachings of Kubo, rather than columns 1 and 2 and corresponding FIGS. 1-2 of Kubo cited by the Examiner, the primary invention of Kubo appears to be FIGS. 3-5, which actually teach the reduction of the modulation transfer function (MTF; or the modulus of the optical transfer function) to zero for specific wavelengths. Applicants disagree with the Examiner's interpretation of the "soft focus effect" provided by Kubo. Applicants respectfully contend that the Examiner's statement as quoted above is inaccurate. The Examiner speculates about effects that the optical filter of Kubo *might* provide over a range of object distances, but these effects are not specifically taught nor discussed in Kubo. Even after a careful review of Kubo, Applicants are unable to find any instance in Kubo of the use of the phrase "depth of focus" or even "extend." It is respectfully submitted that it is improper to

take the teachings of a reference piecemeal; the totality of the prior art must be considered. *In re Hedges*, 783 F.2d 1038, 228 USPQ 685 (Fed. Cir. 1986), MPEP 2145 X.D.3.

It is respectfully submitted that the optical filter of Kubo is essentially a selective diffuser for minimizing spatial detail of light in a selected wavelength range, while not affecting light of other wavelengths, such that the light of the selected wavelength will *not* be in sharp "focus," while light of other wavelengths maintains spatial detail, at a given image plane. That is, Kubo is concerned with providing a "soft focus effect" (i.e., lack of high spatial frequency information) at a given image plane (e.g., a plane of best focus) for a selected wavelength, while providing a "sharp" image - that is, an image replete with high spatial frequency information - at the same given plane for wavelengths other than the selected wavelength. In other words, Kubo is teaching a controlled method of *decreasing image resolution at a specific wavelength* in the focal plane. One skilled in the art will appreciate that the term "soft focus" applies only to perceived sharpness of the image, and not focal distance; the effect realized through Kubo's filter has to do with wavelength-specific high spatial frequency information, not focal distance or depth of field. Kubo teaches the effect on the MTF at a plane of best focus only, not at other planes of focus. In fact, Kubo states the importance of maintaining spatial detail for light that is not in the selected wavelength range, and points out that prior art solutions that rely on "soft focus" fail to do so:

> ...various soft focus lenses and soft focus filters with sharp lenses are provided [in the prior art]. However, since such soft focus lenses and filters produce soft focus effects not only on the facial spots, etc., but also on the other areas of the picture, for example, a dress, hair, etc., a desirable portrait can not be obtained by them. Therefore, a desirable portrait in which the facial spots, freckles, wrinkles, and other common blemishes are reproduced softly <u>and the other areas except for the human skin are reproduced sharply,</u> is not obtained by the above-mentioned device [sic]. Kubo, col. 1, lines 16-26 (emphasis added).

In contrast, the optical system of Applicants' claim 7, as amended, provides an optical mask which modifies the phase of light from an object such that:

> . . . a main lobe of the ambiguity function is broader in v for a given value of u and the PSF has a functionally different form for a given value of ψ, in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the imaging system without the optical mask

> for those given values of u and ψ, over an extended depth of focus larger than a depth of focus formed without the optical mask.

Applicants are unable to find any teaching in Kubo, explicit or implicit, of extending the depth of focus of an imaging system, and respectfully submit that the limitations as provided in amended claim 7 of the present application are not anticipated by Kubo. Therefore, withdrawal of the rejection of claim 7 over Kubo under 35 U.S.C. §102(b) is respectfully requested.

9. – 10. Claim Rejection - 35 U.S.C. §103(a) over Kubo in view of Poon

Claim 8 stands rejected by the Examiner under 35 U.S.C. §103(a) as unpatentable over the above referenced Kubo in view of the article "Optical/digital incoherent image processing for extended depth of field" by Poon et al. (hereinafter, "Poon"). Applicants respectfully disagree and traverse this rejection.

Legal basis for obviousness rejections under 35 U.S.C. §103

The following is a quotation from the MPEP setting forth the three basic criteria that must be met to establish a *prima facie* case of obviousness:

> To establish a *prima facie* case of obviousness, three basic criteria must be met. First, there must be some suggestion or motivation, either in the references themselves or in the knowledge generally available to one of ordinary skill in the art, to modify the references or to combine reference teachings. Second, there must be a reasonable expectation of success. Finally, the prior art reference (or references when combined) must teach or suggest all the claim limitations. [MPEP §2142, citing *In re Vaeck*, 947 F.2d 488,20 USPQ2d 1438 (Fed. Cir. 1991)]

Furthermore, a proposed modification cannot render the prior art unsatisfactory for its intended purpose:

> If proposed modification would render the prior art unsatisfactory for its intended purpose, then there is no suggestion or motivation to make the proposed modification. [MPEP 82143, citing *In re Gordon*, 733 F.2d 900,221 USPQ 1125 (Fed. Cir. 1984)]

Under *In re Vaeck*, there must be: (a) some teaching or suggestion to modify the prior art, either in the reference or based on one of ordinary skill at the time the invention was made, without rendering the prior art unsatisfactory; (b) a reasonable expectation of success; and (c) all the claim elements must be taught. 947 F.2d 488, 20 USPQ2d 1438; see also *MPEP 2142* and *2143*. Under *In re Gordon*, a teaching or suggestion to modify the prior art must not render the prior art

unsatisfactory for its intended purpose. 733 F.2d 900,221 USPQ 1125; see also *MPEP 2143*. Applicants contend that factors (a), (b) and (c) cited in *In re Vaeck*, within the constraint imposed by *In re Gordon*, cannot be satisfied by the application of the Kubo and Poon references to claim 8 as amended.

First, Applicants submit that Kubo and Poon, individually, do not teach the limitations as recited in claim 8. In particular, as discussed above regarding the 35 U.S.C. §102(b) rejection of claim 7 over Kubo, Applicants respectfully submit that the optical mask as taught in claim 7, from which claim 8 directly depends, is not taught nor suggested by Kubo alone. The optical filter of Kubo *reduces* high spatial frequency information imaged at a selected wavelength. Similarly, as discussed in detail in the Response filed on 5 May 2005, Poon teaches the combination of an annular, amplitude filter in combination with digital processing, but Poon alone also does not disclose the limitations recited in amended claim 8.

Second, no conceivable alteration of Kubo's "optical mask" with anything found in Poon results in "an electronic image that is clearer over the extended depth of focus as compared to an electronic image formed by the system and without the optical mask and over the extended depth of focus," as recited in amended claim 8. Applicants respectfully submit that any conceivable modification of the system of Kubo with the teachings of Poon would be unsatisfactory for its intended purpose. In particular, as seen in, for example, FIGS. 3-5 of Kubo, the modulation transfer function resulting from the use of the optical filter of Kubo results in sharp reductions in the modulation transfer functions for specific wavelength ranges. In contrast, Poon specifically teaches *away* from introducing zeros into the optical transfer functions (and, therefore, the modulation transfer functions); that is, Poon teaches to "eliminate the zeros in the OTF of a defocused system" (p. 4614, section II.C of Poon) by proper selection of the radius ratio of the annular aperture, amplitude filter. That is, no suggestion or motivation exists, in the references themselves or in the knowledge generally available to one of ordinary skill in the art, to combine the references. In fact, Applicants contend that, due to the presence of zeros in the modulation transfer functions as seen in FIGS. 3-5 of Kubo, the imaging effects introduced into the image by the presence of the phase filter of Kubo cannot be reversed by any type of post-processing.

Third, Applicants respectfully disagree with the Examiner that Kubo is analogous art that can be combined with the teachings of Poon. It is respectfully submitted that this combination may be suggested only in impermissible hindsight. While the Examiner states that Kubo and Poon are "in the same field of endeavor" [Office Action, page 5], Applicants respectfully disagree. As discussed above, the disclosure of Kubo concerns selectively reducing high spatial frequency information imaged at a specific wavelength range, while maintaining sharp focus outside of the specific wavelength range for a given image plane by using a *phase* filter including a random distribution of phase modifying spots to purposefully reduce the modulation transfer function for that specific wavelength range (see, for example, column 1 lines 22-26 and lines 51-63 and FIGS. 3-5 of Kubo). In contrast, Poon is concerned with extending depth of field using an annular, *amplitude* filter in combination with digital processing to achieve an extended depth of field. Therefore, since Kubo and Poon employ different techniques to achieve different goals, Applicants respectfully submit that Kubo is non-analogous art in a different field of endeavor.

On all of these grounds, a *prima facie* case of obviousness fails to exist for claim 8, and Applicants request reconsideration and withdrawal of the rejection of claim 8 under 35 U.S.C. §103(a).

11. Claim Rejection - 35 U.S.C. §103(a) over Kubo

The Examiner has rejected claim 11 under 35 U.S.C. §103(a) as being unpatentable over Kubo. In this rejection, the Examiner essentially repeats the remarks presented in the above discussed rejection of claim 7 under 35 U.S.C. §102(b) over Kubo and adds:

> The feature concerning the "range ψ" cannot be examined since it is not defined and it is not clear what feature is being described. [Office Action, page 6]

Applicants respectfully traverse.

First, claim 11 has been amended to include language that specifically defines the ambiguity function ψ (also see paragraph **[0075]** of the application as filed). Applicants submit that the definition of ψ in claim 11 is clear to one skilled in the art.

Applicants also submit that the amendments to claim 11 include claim elements that are not contained in, and are not obvious over, Kubo. For example, claim 11 requires at least one

lens, an optical mask and a detector that cooperate to image light from an object to form a stored image, which lens is characterized by at least a length L, a focal length f, a front principal plane and a rear principal plane, and which light is characterized by at least phase and a wavelength λ, the optical mask modifying the phase such that a main lobe of the ambiguity function is broader for a given range of ψ at a given value of u, and the PSF has a functionally different form, in comparison to a main lobe of an ambiguity function and a PSF, respectively, characterizing the imaging system without the optical mask for that given range of the misfocus parameter ψ, defined by the equation: $\psi = \frac{L^2}{4\pi\lambda}\left(\frac{1}{f} - \frac{1}{d_o} - \frac{1}{d_i}\right)$, where d_o is a distance from the object to the front principal plane and d_i is a distance from the rear principal plane to the detector. Kubo does not teach anything about an optical mask modifying phase such that a main lobe of an ambiguity function being broader for a given range of ψ, or a PSF having a functionally different form, in comparison to an ambiguity function and a PSF characterizing a system without an optical mask. Furthermore, as noted above with respect to claim 7, Kubo does not teach extending depth of focus in general, only utilizing the term "soft focus" to describe the effect of decreasing image resolution at a specific wavelength. Kubo's optical mask does not - explicitly or implicitly - have the effect on an ambiguity function and a PSF for a given range of a misfocus parameter ψ as required by claim 11. In fact, Applicants are unable to find any instance of use of the word "misfocus" in Kubo.

For at least these reasons, Applicants respectfully submit that the Examiner's rejection of claim 11 over Kubo has been overcome; reconsideration is requested.

12. - 13. Double Patenting

Applicants note the Examiner's repeated provisional rejection of claims 7-8 and 11 under the judicially created doctrine of obviousness-type double patenting as being unpatentable over claims 75, 87, 88, 94, 95 and 99 of copending Application No. 09/070,969.

14. Response to Arguments

Applicants note the Examiner's use of form paragraph 7.38, as prescribed in MPEP 707.07(f): "Applicant's arguments with respect to claims 7-8 and 11 have been considered but are moot in view of the new ground(s) of rejection." Applicants respectfully remind the

Examiner of the requirement contained in the MPEP paragraph that follows form paragraph 7.38:

> Examiner note:
>
> The Examiner must, however, address any arguments presented by the applicant which are still relevant to any references being applied. [MPEP 707.07(f)]

Applicants note that numerous arguments have been made in previous responses that are still relevant to other references applied in the Examiner's rejections, and request that the Examiner comply with the requirement of MPEP 707.07(f) by answering all of Applicants' arguments herein that are still relevant to other references applied in the Examiner's rejections.

14. Conclusion

In view of the above Amendments and Remarks, Applicants have addressed all issues raised in the Office Action dated 8 July 2005, and respectfully solicits a Notice of Allowance. Should any issues remain, the Examiner is encouraged to telephone the undersigned attorney.

The fee of $400 for the additional two independent claims and the fee of $1020 for a three-month extension of time is enclosed herewith. Applicant believes no other fees are currently due, however, if any fee is deemed necessary in connection with this Amendment and Response, please charge Deposit Account No. 12–0600.

Respectfully submitted,

LATHROP & GAGE L.C.

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